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An Analysis of Groundwater Level Records Obtained at Selected Groundwater Monitoring Sites in New Brunswick

Report prepared for the
Environmental Planning and Sciences Branch
New Brunswick Department of the Environment

by

Christopher N. Clinton

Groundwater Studies Group
Department of Civil Engineering
University of New Brunswick
Fredericton, N.B.

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1. INTRODUCTION

With the increased use of groundwater for private and municipal water supply, it has become necessary to evaluate and determine how to manage the groundwater resource. The management of the groundwater resource is dependent upon good quality groundwater data sampled over space and time. Using the available data, a long-term analyses of the groundwater levels can be carried out to demonstrate some of the applications for which the data may be utilized.

The New Brunswick Department of the Environment has been obtaining data from groundwater monitoring wells since 1979, and actively monitors a network of wells. This network provides the groundwater level data that is used for this study.

The objective of this report is to:

1. Review the groundwater data monitoring system used in New Brunswick.

2. Demonstrate how the available data can be presented in order to enhance the use of the data for management purposes.

3. Demonstrate how the data may be used in studies related to the response of groundwater levels to recharge.

2. NEW BRUNSWICK GROUNDWATER MONITORING NETWORK

At present (1991) there are 36 wells in the province that are actively monitored to record groundwater elevation. Of these wells, 28 are monitored by the New Brunswick Department of the Environment (NBDOE), 8 are monitored by the Water Survey of Canada, Environment Canada. Of the 36 wells, 25 are equipped with recorders while the remaining 11 are recorded manually on a monthly basis. The location of the monitoring wells in the network are shown in Figure 2.1.

2.1 Recorders

The following five types of recorders are in service within the groundwater monitoring network in New Brunswick :

i) A-35 Metric
ii) A-71 Metric
iii) F-Type Imperial
iv) Telemark II
v) Telog

All of the recorders in the network are manufactured by Leupold and Stevens. The lack of standardization of equipment is largely a result of the fact that most of the original units in the network were obtained from other organizations (Brinsmead, 1984).

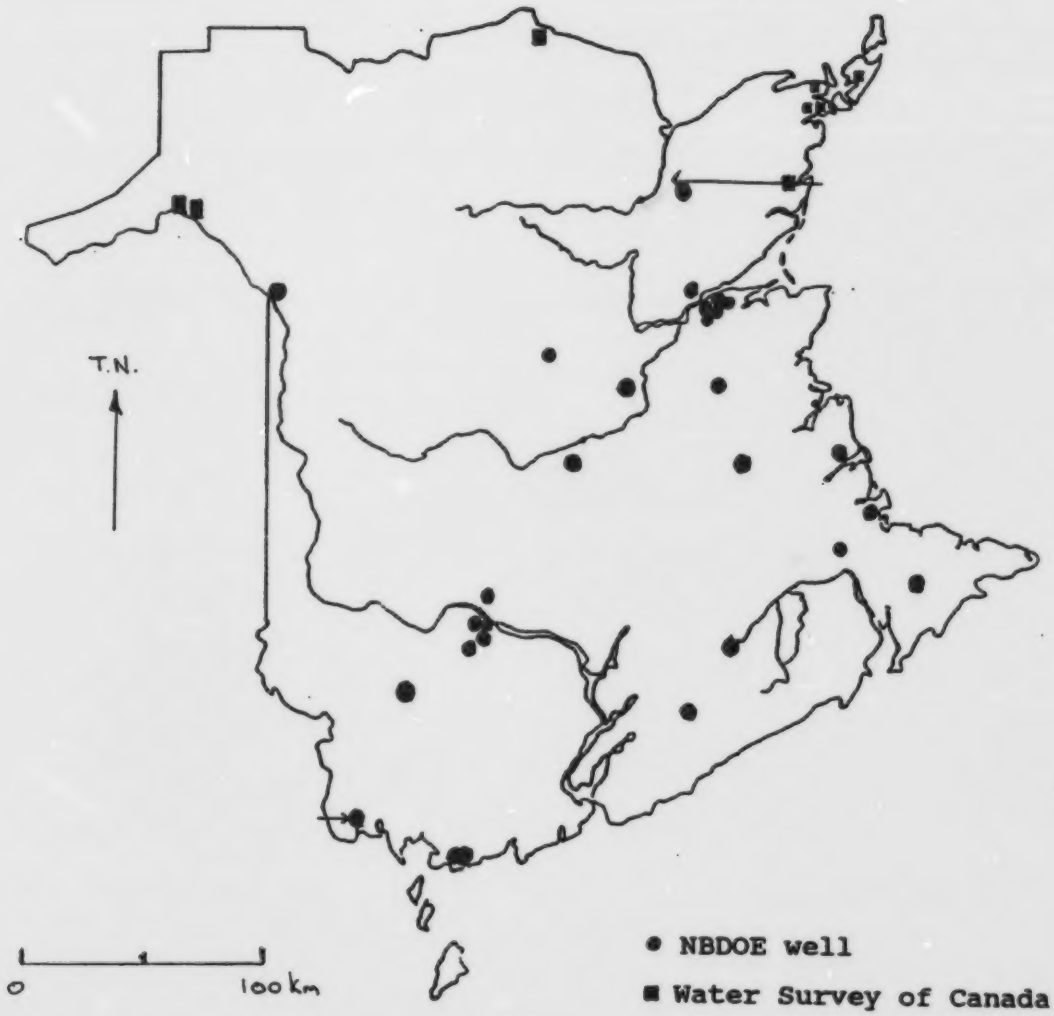


Figure 2.1 Location of the groundwater observation wells in New Brunswick.

The first three types of recorder are strip chart recorders, and require the use of a float and a counter weight inside the well casing to record the variations of the groundwater level (Figure 2.2). The essential differences between the three recorders are the length of available recording time and the units in which the data are recorded. The A-35 recorder, an older model of the A-71, is used only at one monitoring well site in the province. Both record the groundwater variations in SI units. Of these two models, the Federal government uses only the A-71 recorder.

The A-35 and A-71 recorders are powered by a spring, much like a clock. The length of recording time available before it becomes necessary to change the chart for these recorders may range from four and a half to six months depending upon the type of spring used.

The F-Type Imperial recorder, also a strip chart recorder, has a recording period of only 8 to 32 days, depending upon the gearing that is used. This recorder has a strip chart that is placed over a drum (Figure 2.3). The chart must be replaced at the end of the period. Unlike the A-35 and A-71 recorders, the F-Type is operated by a one D battery, which must also be replaced on a regular basis. The F-Type recorder is designed to record groundwater variations in Imperial units.

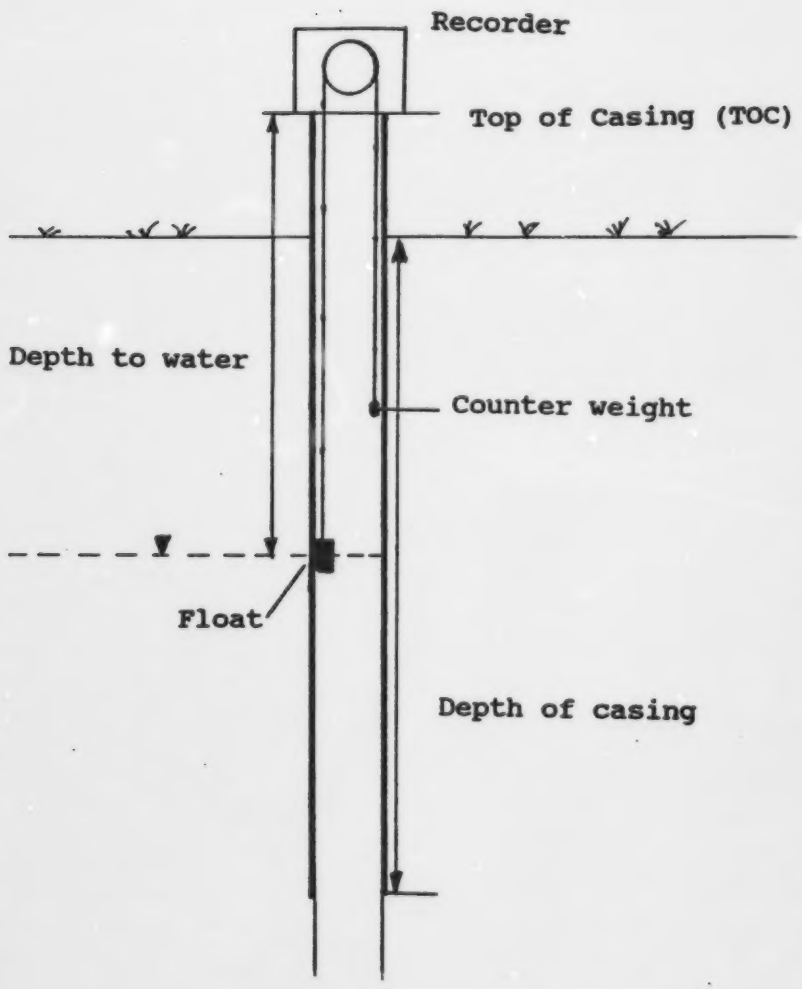


Figure 2.2 Definition sketch of a monitoring well.

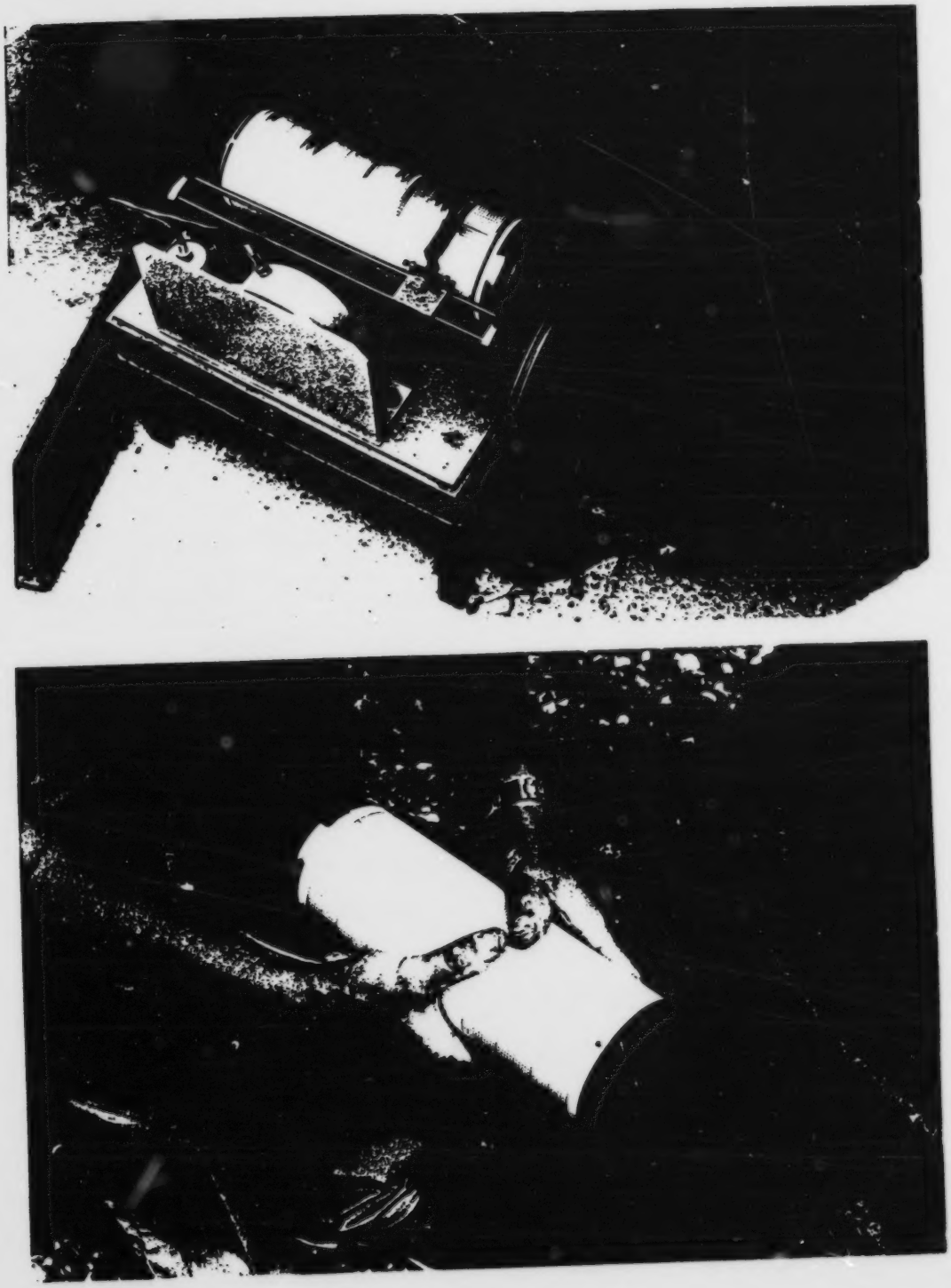


Figure 2.3 F-Type strip chart on drum and being replaced.

The Telemark II and Telog recorders are both in operation at the New Maryland observation well. The Telemark II uses a float, as do the previous recorders described but instead of a strip chart recorder, it is hooked up to an encoder that records the groundwater level, to the nearest millimetre, at programmed time settings (from a computer). This encoder is attached to a modem within the well building that allows for the information to be downloaded over a telephone line to a computer at NBDOE. Unlike the other recorders the Telemark II is set to record changes in elevation of the groundwater from a known reference elevation.

The final recorder in the network is the Telog. This recorder works by way of a pressure transducer that is inserted into the well. The groundwater level is based upon the pressure exerted by the water on the pressure transducer. Like the Telemark, it is also hooked to an encoder and modem which allows the data to be downloaded to a computer at NBDOE. This unit takes well level readings every second and then averages the values over an hour. The Telemark II and the Telog both have their own software that is used to control the recorder over the telephone lines from a computer.

2.2 Site Maintenance

The present New Brunswick groundwater monitoring network is

maintained by one person who visits the 28 wells maintained by the Provincial Government. Having one person visiting the sites allows for uniformity in the well management program. It assures regular visits to the wells, replacement of strip charts and the setting up of recorders. This uniformity reduces human error that may occur if more than one person maintained the network.

Since the F-Type recorder requires that the strip chart and battery be replaced, at the maximum, every 32 days, monthly field trips are necessary. Where the recorder is not hooked up by modem to the office, it is impossible to ensure that the recorders are operating properly and these trips allow for inspection of each well site. For example, the observer can readily determine if the float has become stuck on the side of the casing (Figure 2.4).

During the field trips to verify the recorder results, a depth to water measurement is taken by using an electrical tape. The difference between the previous months reading and the present reading, indicates the net fluctuation of the groundwater level over the period. This change may then be compared to the value obtained from the strip chart to provides a quick check on the recorder.

Besides the regular replacement of the strip charts and batteries, these trips also allow for general inspection of the sites to ensure that the well, building and equipment have not been

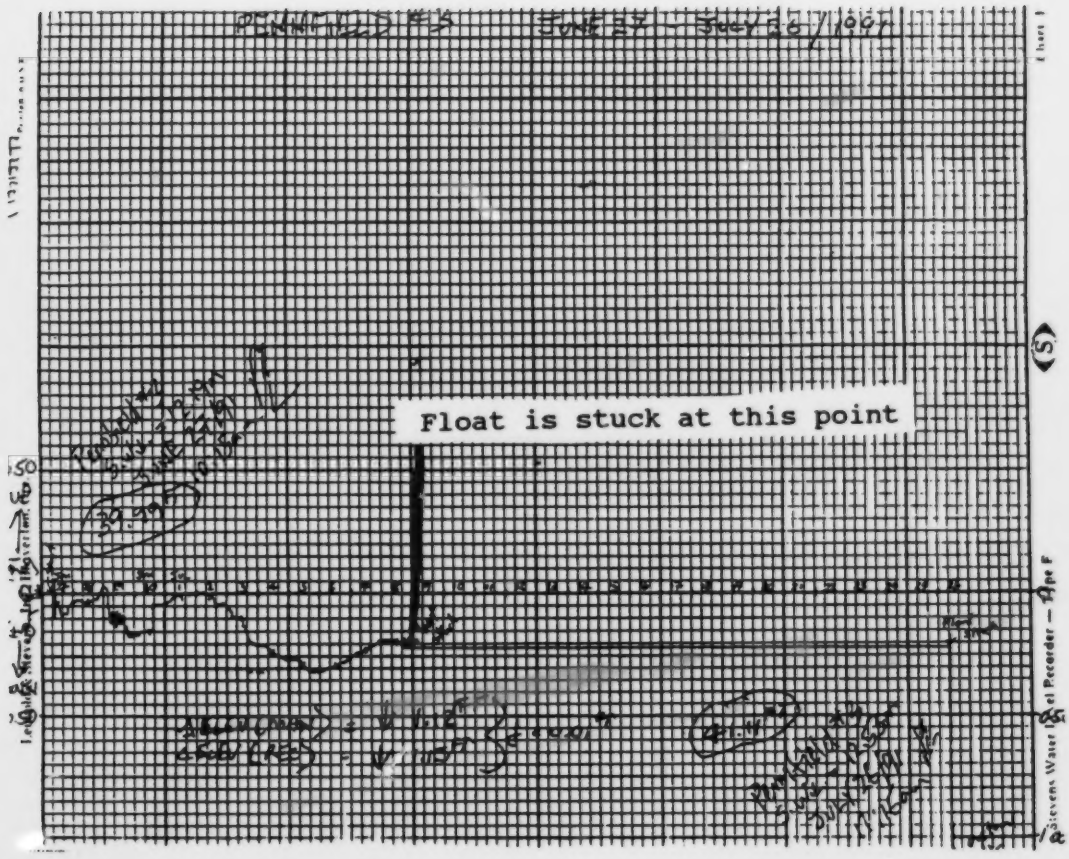


Figure 2.4 Strip chart showing an example of lost data (straight line) due to float being stuck on side of casing. From Pennfield #3 well between June 27 and June 26, 1991.

vandalized. Vandalism to the well ranges from the well being blocked with stones and debris to the well building being knocked over and the equipment being destroyed. For this reason, the more recent wells are enclosed by a short section of concrete culvert that has a steel lid attached (Figure 2.5). This method of well protection attracts less attention than the previous wooden sheds (Figure 2.6) and it requires more effort to break into them.

2.3 Data

The data obtained from the strip chart recorders, that is the 12:00 (noon) value, are transferred to an electronic spreadsheet for each day of the month. With the use of the spreadsheet (i.e. LOTUS 1-2-3), the values determined from the F-Type recorder charts are easily converted from Imperial to SI units.

At present, 26 of the 28 wells that are managed by the Province measure a variation of the water level from a specified value. This value is the measured value of depth to water taken with a tape measure before the recorder is reset to record for the next month. This method requires that the elevation of the top of casing (TOC) be known if the water levels are to be converted to elevation. Since the use of a spreadsheet program at NBDOE was started in January 1989, the conversions of data from depth to water to elevation are accomplished by the use of simple formulas.

Figure 2.5 Concrete culvert with steel lid surrounding observation well and recorder at Pennfield.

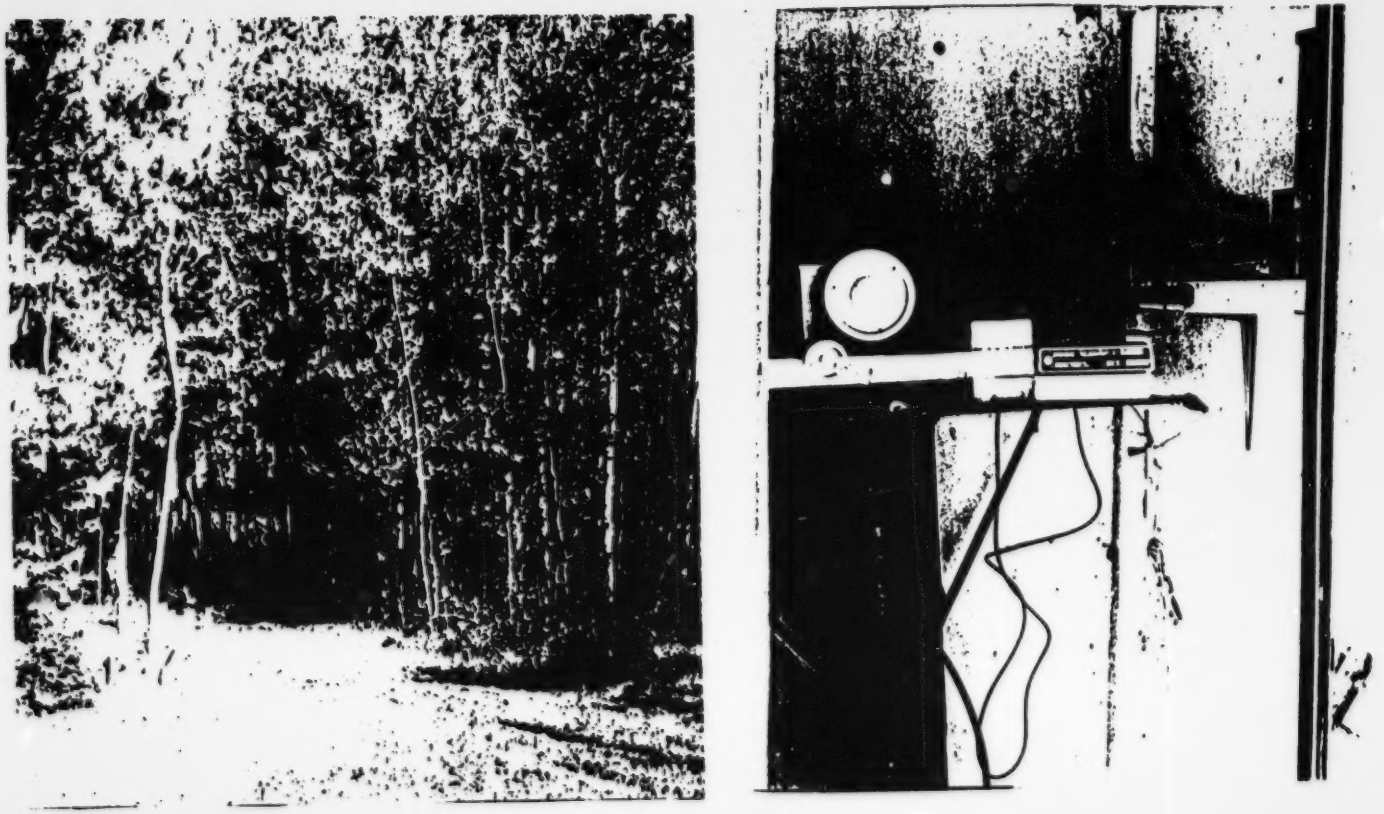


Figure 2.6 Wooden shed surrounding the observation well and recorders (Telemark II and Telog) at New Maryland.

This procedure has been an improvement over the previous method of just reporting depth to water. The Federal government have always reported the elevation of the water in the monitoring well.

Though the value of TOC generally remains constant, problems may arise due to settlement of the casing, frost heave or unrecorded changes made to the casing length above ground (that is, it may have been extended or shortened). Periodic checks from an established bench mark located at some distance from the monitoring well are made to ensure that the elevation of the TOC is within one millimetre of the initial elevation.

3. SITES FOR THIS PROJECT

3.1 Site Selection Criteria for this Project

The purpose of this study was to perform a detailed, long-term analyses of groundwater level data from selected groundwater monitoring sites in New Brunswick in order to demonstrate some of the applications for which the data may be utilized. The basis for selecting the observation wells for the study were :

i) Length of record
ii) Range of groundwater level fluctuations
iii) Number of wells in area
iv) Depth to water
v) Effect of pumping in nearby wells.

3.1.1 Length of record

A long period of record was essential in order to allow a thorough study of the variation of the groundwater levels over an extended period. The lengths of record varied between eight and eleven years, but when selecting wells for this study it was also necessary to view the cumulative amount of data available. In some cases data for a well may be missing for an entire year because the recorder was not operating or the data could not be found.

3.1.2 Range of groundwater level fluctuations

In order to obtain dramatic results when using SURFER, a contouring software package, the selection of those wells with groundwater level fluctuations of one metre or more was established as a requirement.

3.1.3 Number of wells in area

In order to make comparisons between wells and present general statements about the aquifers in which the wells are located, it was considered that a series of wells, within close proximity to one another in one area, should be considered. In the network there are five locations that have more than one monitoring well.

3.1.4 Depth to water

Though depth was not a general concern when initially selecting observation wells for most of the analysis to be performed, it was a concern when selecting a well to examine the response of groundwater levels to recharge. For that part of the study, it was required to have a shallow well with a near surface groundwater table. This would allow for comparisons to be made between recharge, groundwater levels and surface runoff in a gauged

river.

3.1.5 Effect of pumping in nearby wells

Again, as with depth, the effect of pumping on groundwater levels was not a general concern when selecting observation wells, except for the evaluation of recharge to groundwater. For that study, it was necessary to have a well that was far enough away from large residential or industrial areas that would affect the behaviour of the groundwater levels. By selecting a site that appeared to be unaffected by pumping, comparisons could be made between recharge and groundwater levels.

3.2 Site selected for this Study

The location of the groundwater monitoring wells in the New Brunswick network are shown in Figure 2.1. The wells that were selected for the study are listed in table below (from Brinsmead, 1984). The table also lists general information concerning each well, based on the criteria listed in Section 3.1.

Well No.	Well Name	Location	TOC (m)	Depth (m)	Depth of casing below ground (m)
BO-1	Chatham Air Base	Chatham	20.73	123	18
BO-2	Chatham RCP	Chatham	26.76	116	
BO-4	Chatham Industrial	Chatham	29.68	46	
AM-1	New Maryland	New Maryland	109.13	91	12
91BL009	Tracadie	Tracadie	20.15	20	6
91BL012	Shippegan	Shippegan Rue. 15	4.02	26	
91BL011	Lameque	Lameque Rue. de Pecheurs	9.50	30	10
91BL008	Caraquet Fed.	Caraquet	22.42	15	10

Well No.	Period of record to present	Type of recorder	Affected by pumping	% data recovery (beginning - 1990)
BO-1	78/07 -	A 71 Metric	No	83
BO-2	81/07 -	A 71 Metric	No	90
BO-4	81/10 -	A 71 Metric	No	93
AM-1	79/04	Telemark II Telog	Yes	80
91BL009	82/11 -	A 71 Metric	Yes	75
91BL012	80/07 -	A 71 Metric	Yes	69
91BL011	80/05 -	A 71 Metric	Yes	66
91BL008	81/06 -	A 71 Metric	No	96

4. DATA FILES

For this study, the storage and presentation of any groundwater level data had to be compatible with NBDOE existing hardware and software. All the data manipulation and graphing were done using LOTUS 1-2-3 (v2.2) and SURFER. Although NBDOE does not own a copy of SURFER, it was assumed that it would be purchased.

4.1 Description of Software

4.1.1 LOTUS 1-2-3

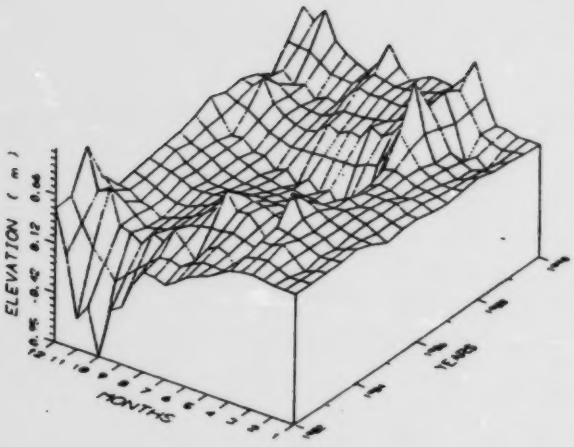
LOTUS 1-2-3 is an electronic spreadsheet that allows the user to manipulate data in rows and columns. It has the capability of handling 8192 rows and 256 columns. Though LOTUS may handle that amount of data, it is important to realize that without expanded memory the computer can only utilize a portion of the potential storage (approximately ten years of daily data). This is important because of the long data sets that may result from a number of years of data collection, particularly when dealing with daily or hourly data.

The graphing capabilities of LOTUS are also somewhat limited, providing five types of graphs, one independent variable and six dependant variables.

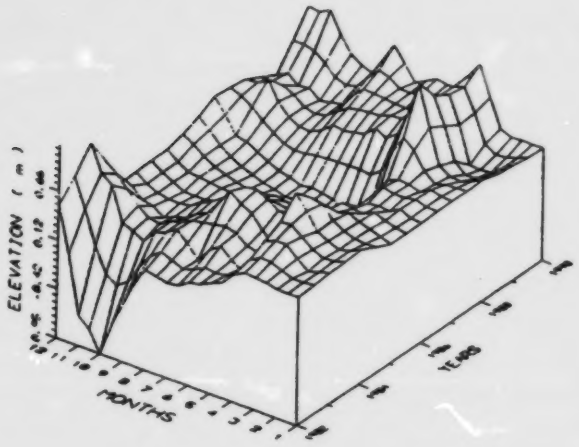
4.1.2 SURFER

SURFER is a quasi 3-dimensional contouring package for strings of data. It is capable of importing both LOTUS and ASCII files through SURFER's **Grid** menu, which is set up in a spreadsheet format. But this spreadsheet lacks the power that LOTUS has to manipulate data. It is best that all data manipulation be done on LOTUS before being imported into SURFER. As with LOTUS, SURFER also has limited memory, it will only contain 14,000 rows and 26 columns of data (approx. 38 years of daily data), depending upon the computer's available memory.

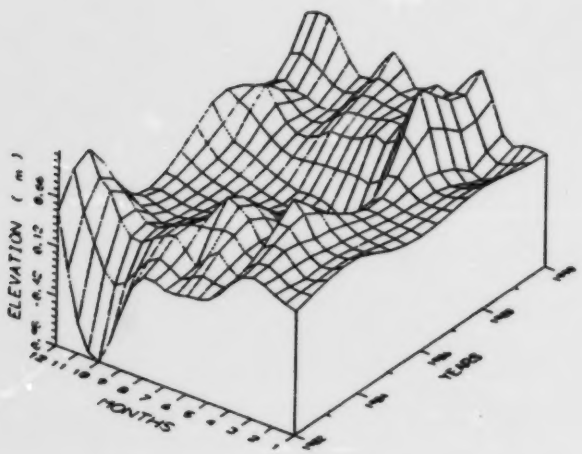
When griding on SURFER, the user has the option of selecting one of the following three methods of interpolation (Figure 4.1): inverse distance, kriging, and minimum curvature. Data points which are used in the inverse distance option are weighted such that the influence of one data point on another declines with distance from the point being estimated. The kriging option use the regional variable theory technique called kriging where the kriging algorithm assumes an underlying linear variogram. The minimum curvature option calculates the grid based on the initial values of the grid elements. It then attempts to smooth the gridded surface by applying an equation repeatedly to the surface with each application counted as one iteration (Golden Software, 1990).



a) Inverse distance method of interpolating grid to fit data.



b) Kriging method of interpolating grid to fit data.



c) Minimum curvature method of interpolating grid to fit data.

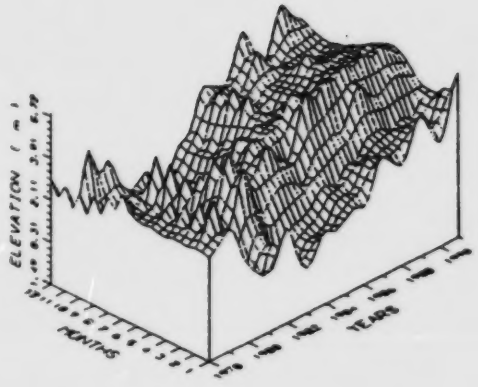
Figure 4.1 Three methods of interpolation using SURFER. Shippegan observation well from 1982 to 1990.

From the **Grid** option to the **Surf** option, the user may then view and orientate the surface in any desired manner. This may be done by rotating the plot about the Y and Z axes (Figure 4.2).

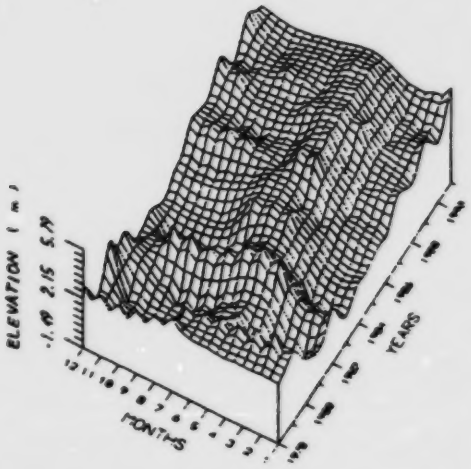
Though SURFER is a powerful software package, it does lack the ability to use repeating sets of text as a position in space (i.e. JAN, FEB, MAR,...) and is slow and awkward when working with daily data. Also because of its method of blanking data points from the grid, the results obtained are not truly representative of the actual available data set. Even with these limitations, the output provides the water resource manager with a visual image that shows the primary features of the groundwater level regime for a particular well over time.

4.2 Files

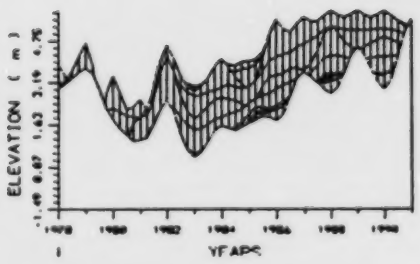
The files used throughout this work must be meaningful to the task that is being performed. To accomplish this, the files are best stored within separate subdirectories that are tied to the well name or number. By using this method of storing files in separate subdirectories, the same file name may be used for similar files at different observation wells. For example, when performing moving averages, the completed moving average may be stored as a file called "MOVEAVG.WK1". This file name may then be used for the same functions in a different subdirectory. A list of the subdirectories and files used in this study are presented in



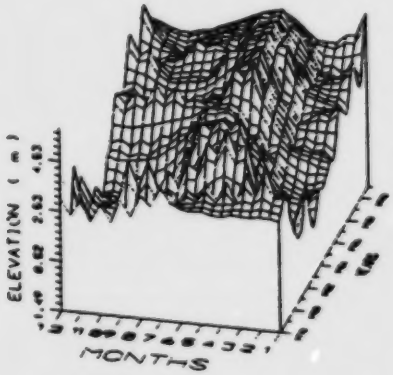
a) rotated 225^0 about z-axis, 30^0 about y-axis.



b) rotated 210^0 about z-axis, 60^0 about y-axis.



c) rotated 270^0 about z-axis, 0^0 about y-axis.



d) rotated 195^0 about z-axis, 25^0 about y-axis.

Figure 4.2 SURFER plots rotated about the Y and Z axes. Chatham Air Base from 1978 till present.

Appendix A.

The initial spreadsheet format for daily data (Figure 4.3) is a continuation of what the NBDOE is presently using. This spreadsheet is stored as a template that is retrieved and used for inputting new data. This method of recording data as a spreadsheet for each year allows for easy manipulation. All other files for data manipulation can be created from this basic file format.

4.3 Missing Data

The ability to work with missing data is not a problem. When using both LOTUS, SURFER, any blanks within the data set are ignored. This is convenient when working with daily data since the number of days in a month differ from 28 to 31. Though there is the possibility of inserting a flag number (-9999) in the place of missing data or where no data exists, it would create problems when using the functions required in the software packages (i.e. Statistics and Griding). No flags are used in the basic data files for this study.

In an effort to ease the evaluation of the length of record available, a Ghant type chart may be produced (Figure 4.4). This type of chart provides an immediate impression of the amount of missing data and indicates how the available data is distributed

WELL LOCATION: DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
DAY 1												
DAY 2												
DAY 3												
DAY 4												
DAY 5												
DAY 6												
DAY 7												
DAY 8												
DAY 9												
DAY 10												
DAY 11												
DAY 12												
DAY 13												
DAY 14												
DAY 15												
DAY 16												
DAY 17												
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DAY 20												
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DAY 22												
DAY 23												
DAY 24												
DAY 25												
DAY 26												
DAY 27												
DAY 28												
DAY 29												
DAY 30												
DAY 31												
TOTAL	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
MEAN	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
MAX	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
MIN	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR

Figure 4.3 Example of spreadsheet template used to store daily groundwater levels.

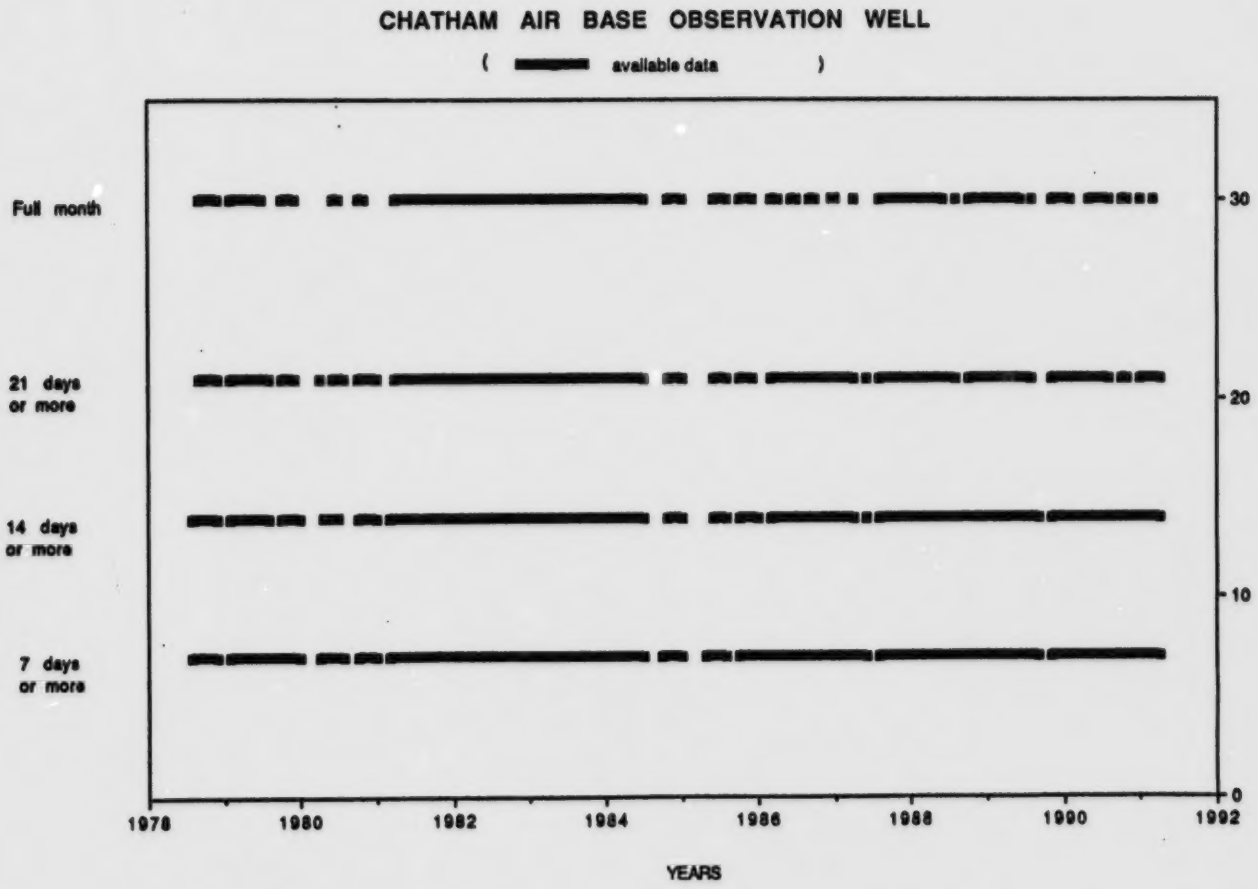

Figure 4.4 Ghant chart showing the distribution of available data for the Chatham Air Base.

over the years. (Note: Because of LOTUS' limited graphing capabilities, this chart was produced on the Apple Macintosh.)

4.4 Quality Control

With the large amount of data entry that is required for each well, errors will occur. Although it is sometimes difficult to discover a data entry error, the best method is to view the daily data over the year or month. This will show any extreme variations that may require checking. Commonly, order of magnitude errors resulting from improper keystrokes are identified by this method.

5. DATA PRESENTATION

5.1 Statistics

The statistics for each month of a year or for each month over the length of record were calculated for selected wells. The basic statistics (mean, maximum, minimum and standard deviation) are all functions that are available in LOTUS. Plotting these basic statistics allows for statements to be made about the behaviour of the groundwater regime over time.

Figure 5.1 shows that the monthly mean, maximum, minimum and +/- 2 standard deviation values do not vary much from what NBDOE produces each month for their groundwater resource paper. Maximum and minimum values closely follow the +/- 2 standard deviation values which suggest that the groundwater levels are more or less normally distributed. If the monthly mean water levels for a particular month were normally distributed, then 2.5 percent of the values would be greater than 2 standard deviations above the mean and 2.5 percent of the values would be less than 2 standard deviations below the mean (a valid assumption if the period of record was in excess of thirty years). Based on the assumption that the water levels are normally distributed, the current Province of New Brunswick Statement on Water Resource Conditions provides a useful assessment when reporting monthly water levels as above or below normal.

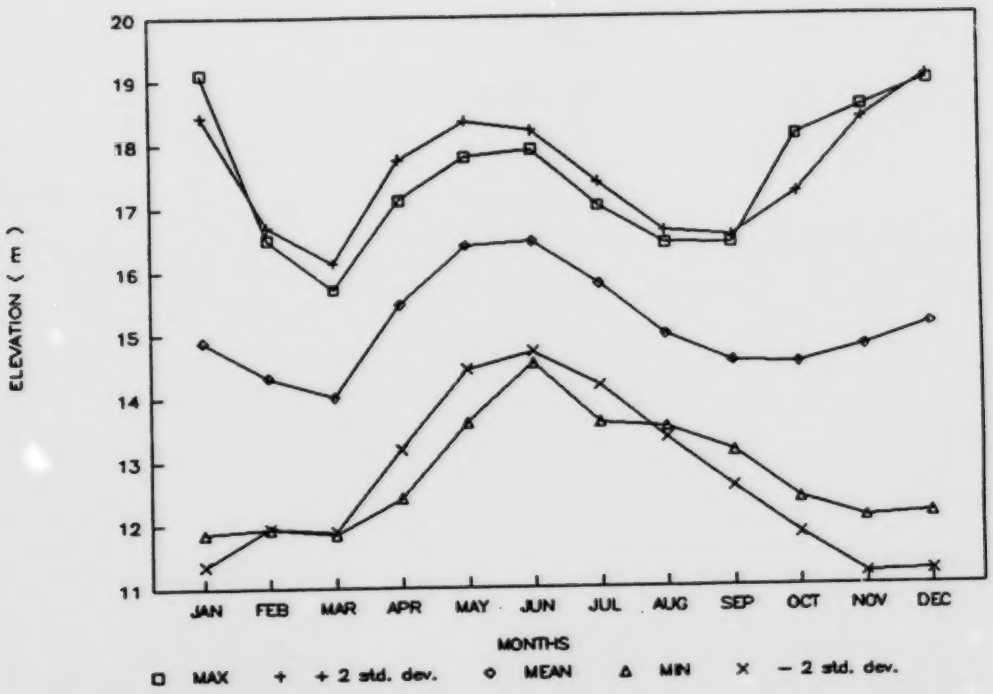

Figure 5.1 Basic statistics characterizing the behaviour of the groundwater at the Chatham Industrial Park well (1981 - 1991).

The skewness coefficient for each month over the period of record were also calculated using the following equation:

$$C_s = \frac{n\sum (x-\bar{x})^3}{(n-1)(n-2)s^3}$$

A negative skewness coefficient indicates that the distribution is skewed (or smeared) to the left and a positive skewness indicates that the distribution is skewed to the right. A symmetrical distribution has a skewness coefficient of 0.0. The normal distribution is symmetrical and has a skewness coefficient of 0.0.

The variation of the skewness coefficient for the monthly data over the ten year period of record at the Chatham Industrial Park observation well is presented in Figure 5.2. The values of the skewness coefficient are negative between January and August and then become positive for the remainder of the year.

Moving averages for the longest and consistent periods of record were also performed. Using daily well levels, moving averages of three, seven, fifteen and twenty-one days were evaluated (Figure 5.3). Moving averages smooth the daily data to eliminate the effects of local peaks (spikes) and provide a better representation of the general groundwater regime than the non-smoothed data. Figure 5.3 suggests that a seven day moving average effectively eliminates the spikes and maintains the shape of the graph.

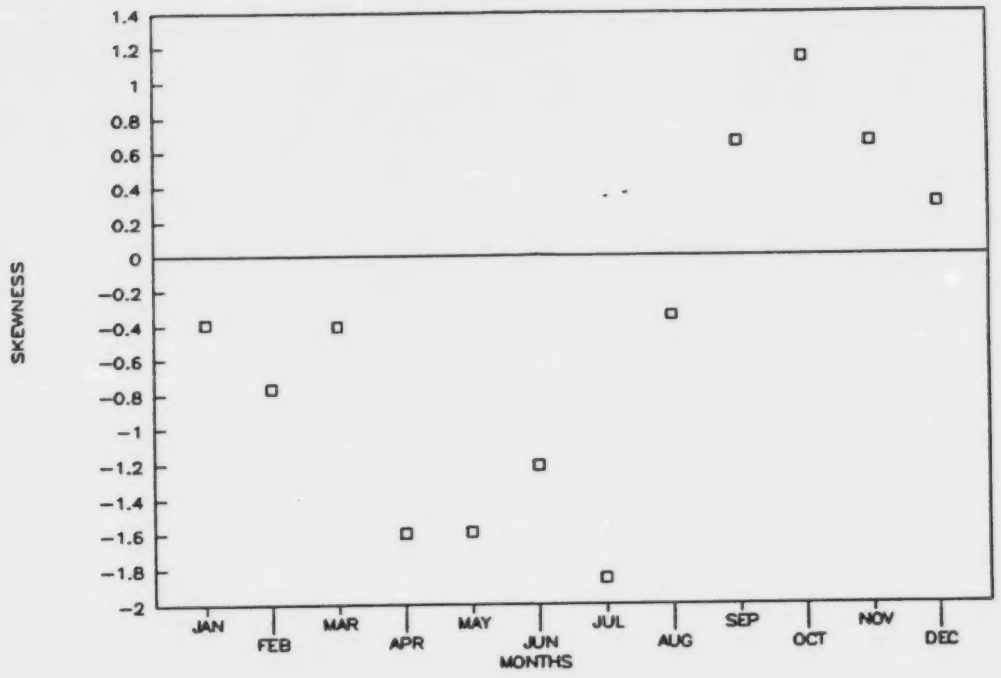

Figure 5.2 Values of skewness coefficient calculated from monthly mean groundwater levels at the Chatham Industrial Park well (from 1981 - 1991).

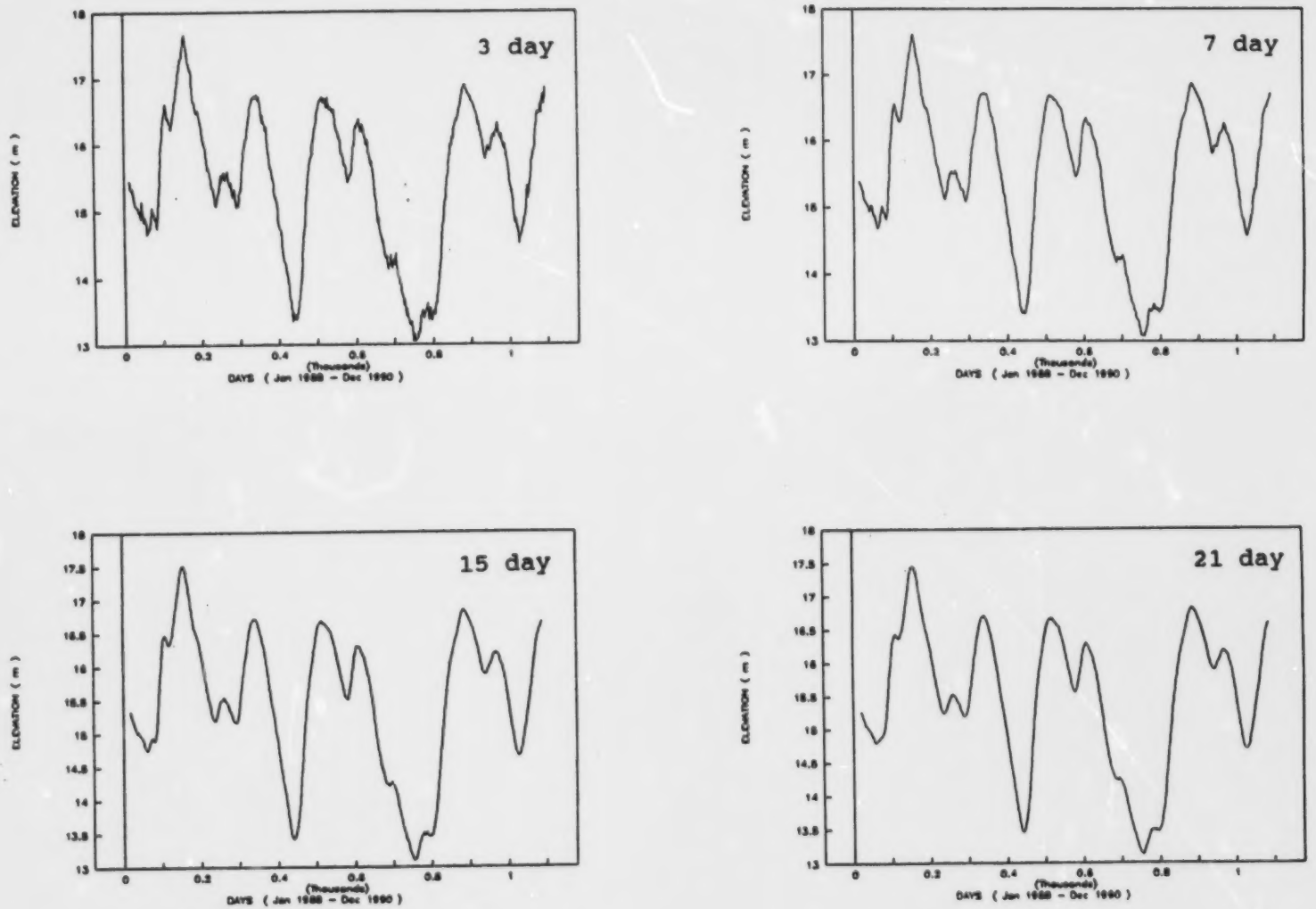

Figure 5.3 Moving averages for a three year period of record at the Chatham Industrial Park observation well (1981-1991).

5.2 Visual Presentation

Visual representation of the groundwater levels over an extended period of time, provides an immediate impression of the groundwater regime. The visual impression created by pictures and graphs is generally more effective than presenting a list of numbers when explaining the behaviour of groundwater levels over the year and over the period of record.

The format of the visual presentations of the groundwater levels is from an overview perspective (yearly) to the most detailed perspective (hourly).

5.2.1 Yearly

Figure 5.4 presents a broad overview that characterises the regime of the groundwater levels at the Chatham Industrial Park over the past eleven years. The mean yearly values shown for the period of record indicate that the groundwater level declined between 1981 and 1985 and has since continued to increase.

Figure 5.5 presents the groundwater regime in slightly more detail. The SURFER plots provide a quasi 3-dimensional representation of variation of monthly levels over the period of record. This Figure is based upon the mean monthly elevation over the period of record and shows the seasonal variation of the

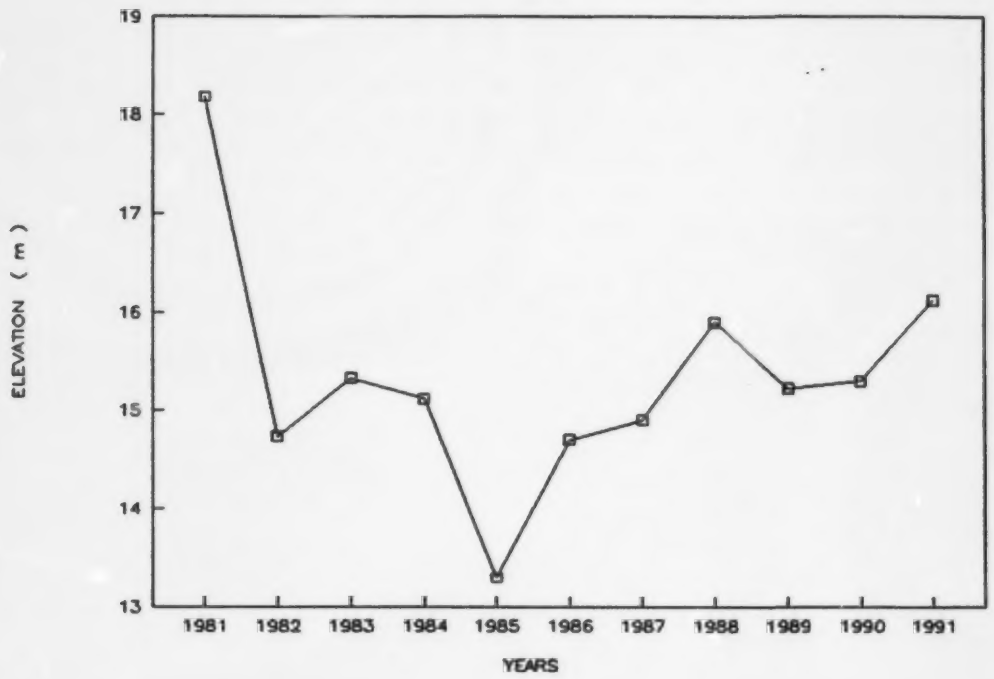

Figure 5.4 Yearly averages of groundwater levels at the Chatham Industrial Park monitoring well (1981 - 1991).

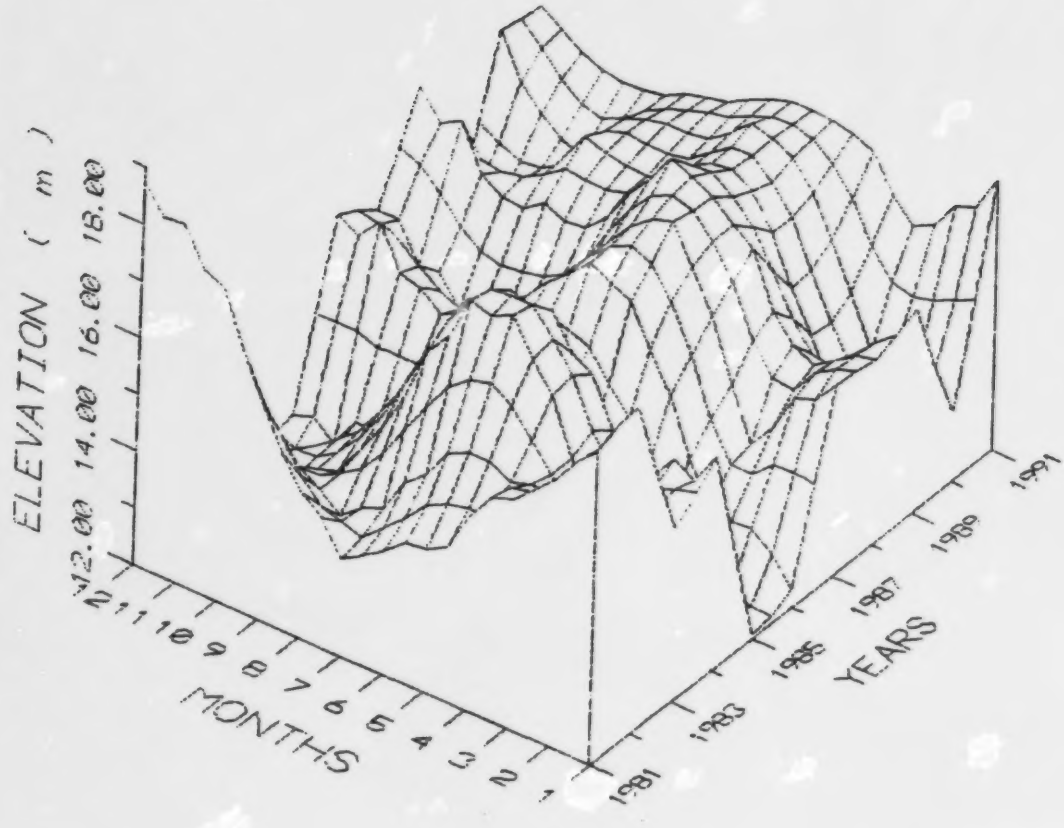

Figure 5.5 SURFER plot of the monthly mean groundwater levels at the Chatham Industrial Park monitoring well.

groundwater levels that occurs. The characteristic ridge that occurs over each year represents the significant recharge that takes place in the months of April and May. The plot also allows for a quick visual evaluation to be made concerning the groundwater levels (i.e. continual decline or increase), or give indications as to climatic conditions during a particular season. As an example, Figure 5.6 shows the behaviour of the New Maryland well. The low values for groundwater elevation in 1987 may suggest a small amount of recharge, rainfall and snowmelt in the beginning of the year.

5.2.2 Monthly

When plotting yearly data, it is not necessary to have complete sets of data. Because of the large amount of data collected in a year, missing data (a month or more) would not represent a large loss when averaging. When using SURFER, some missing data do not greatly affect the results because of SURFER's ability to interpolate between points. But when looking at data on a monthly basis it is necessary to have a relatively complete data set for each month.

As an example, from the SURFER plots, the data may be divided into yearly values for a given month (Figure 5.7) or mean monthly values over a given year (Figure 5.8). These graphs are essentially <u>slices</u> of the SURFER plot, and allow for seasonal and

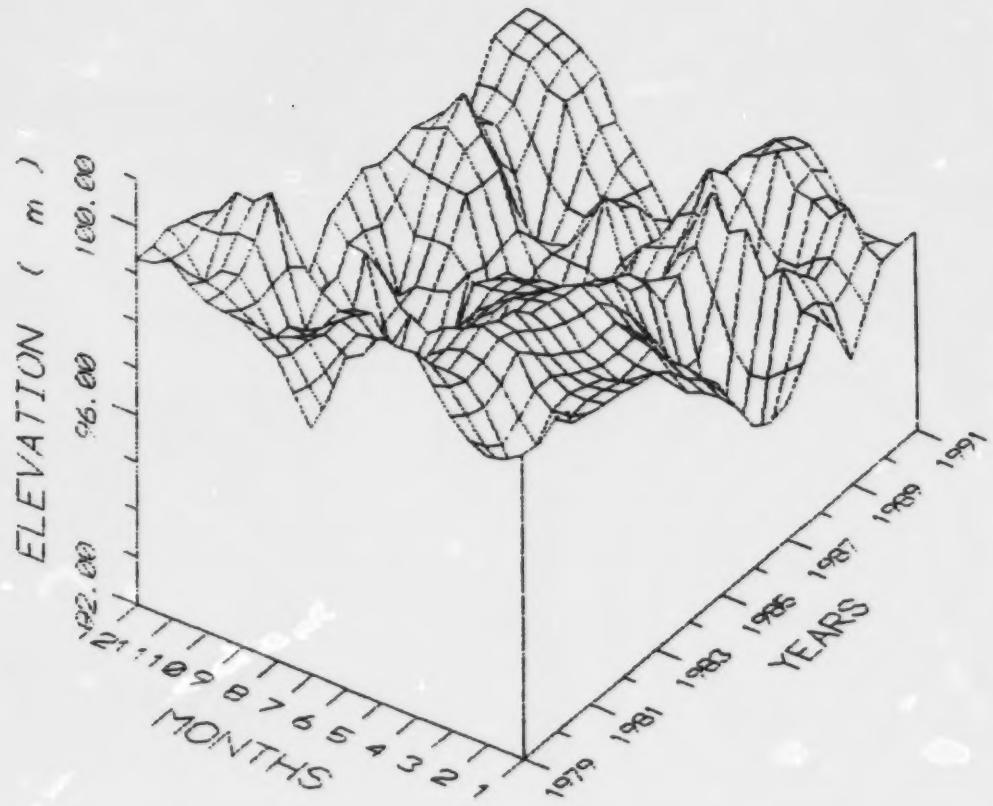

Figure 5.6 SURFER plot of the monthly mean groundwater levels at the New Maryland monitoring well.

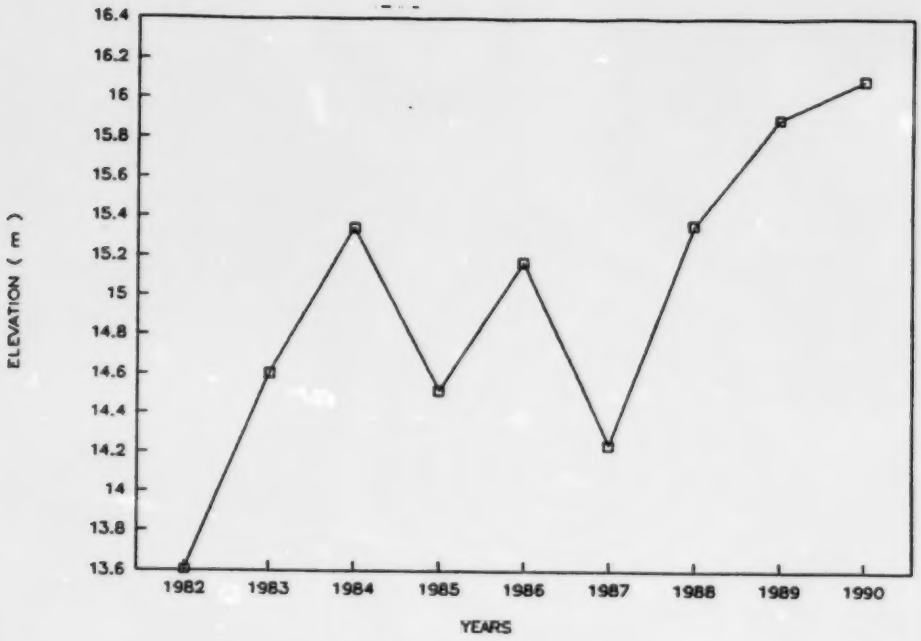

Figure 5.7 Monthly mean groundwater levels for the month of August between 1982 and 1990 at the Chatham Industrial Park observation well.

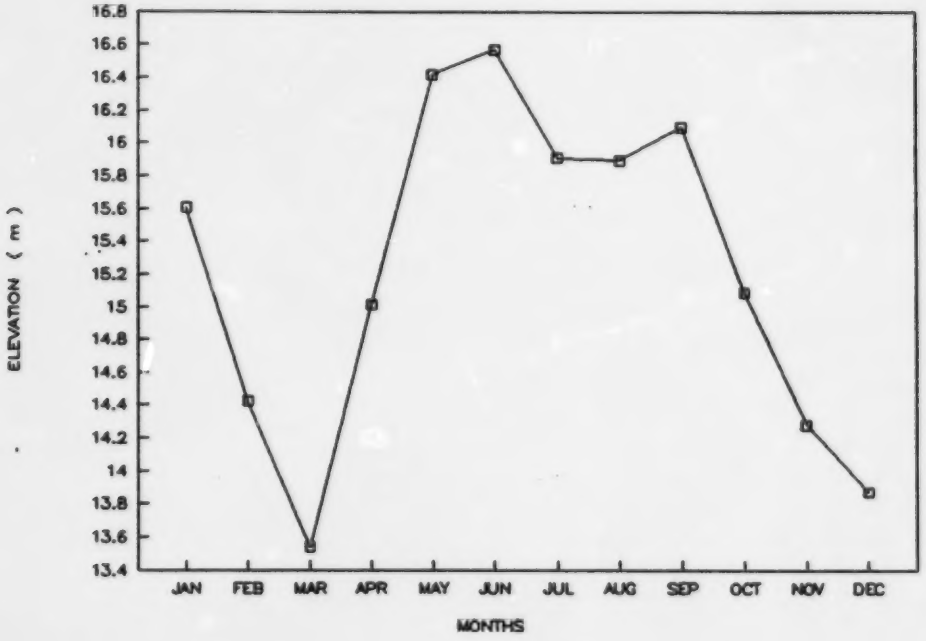

Figure 5.8 Monthly mean groundwater levels for 1989 at the Chatham Industrial Park observation well.

yearly trends to be observed (i.e. a typical two peak recharge event) and events that may have been " hidden " from view on some SURFER plots.

Where there are data for the longest and most consistent period (i.e. data for each month over a number of years), elevation-duration curves may be obtained. These curves provide a numerical value of Percent of time groundwater levels are below a particular elevation (Figure 5.9). It should be noted that this value is not a probability, but a percentage based upon the available data set. Such curves are extremely useful when evaluating the groundwater levels in a particular year.

5.2.3 Daily

For daily data, the amount of data and period of record is important. When working with daily data it is necessary to have data for the longest consistent period (i.e. full month of record and complete years). With this requirement, the available information may be examined in detail over a specific year or longer period of record.

The use of daily data allows for comparisons to be made concerning the representativeness of the mean monthly values of the groundwater levels (Figure 5.10). In this case the mean monthly

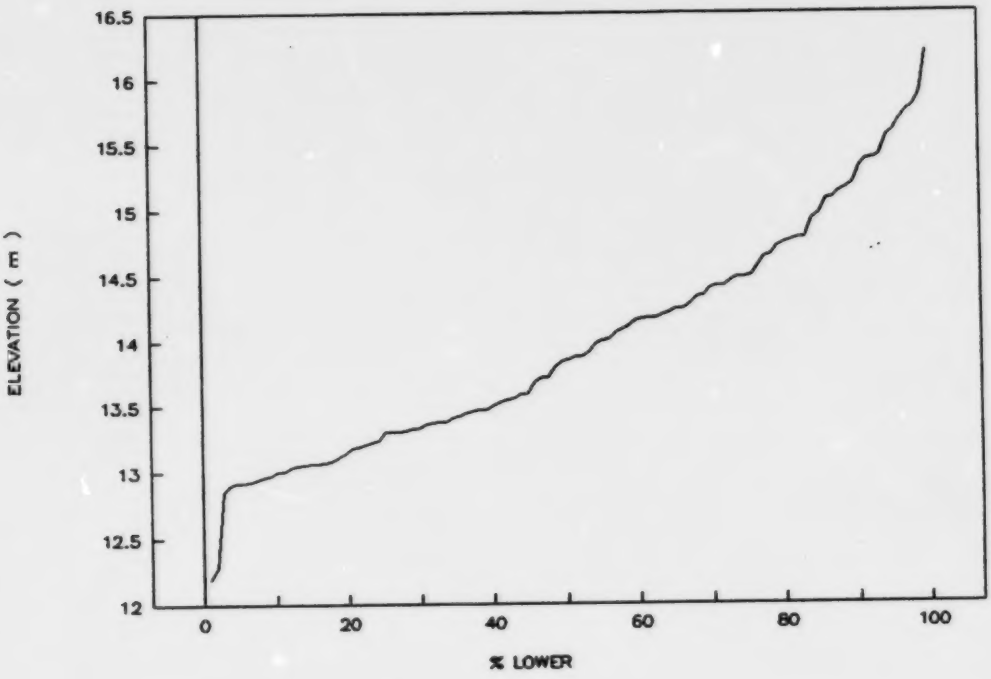

Figure 5.9 Elevation duration curve based on monthly mean groundwater levels at the Caraquet observation well (1982 to 1990). Percent of time that the groundwater was below a certain elevation.

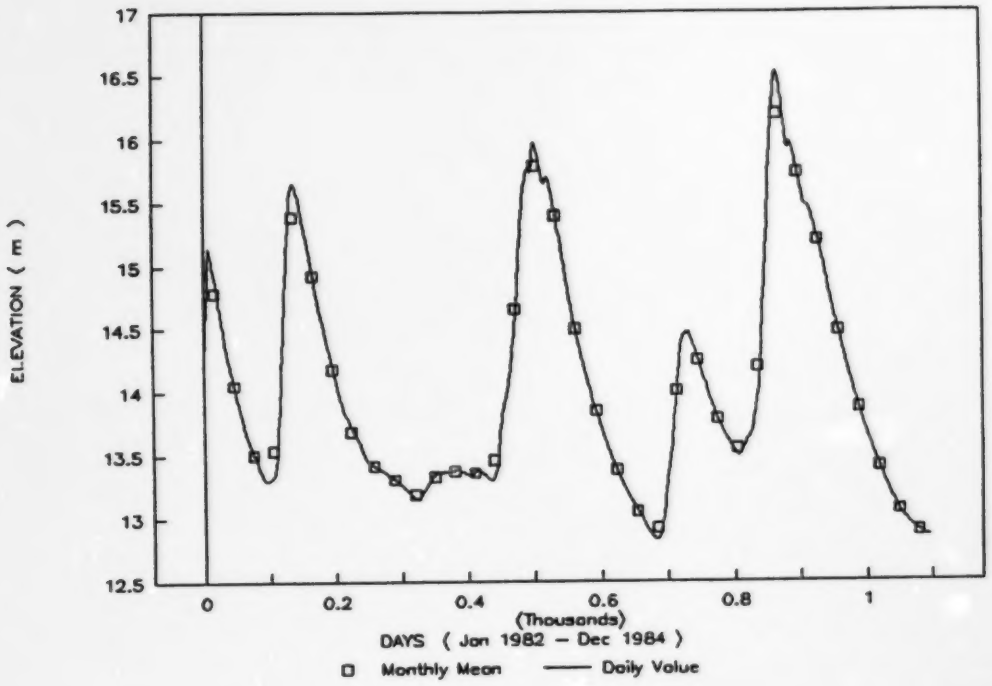

Figure 5.10 Comparison of monthly mean and daily groundwater levels for the Caraquet well between 1982-1984.

values follow the daily value line very closely and only deviates during the peak recharge events. Another comparison that can be made is between the mid-monthly and mean monthly values. Again, both of these variables follow very close to each other, with the mid-monthly value picking up the extreme points (Figure 5.11) better than the mean monthly values.

The results of graphing the daily and the mean monthly values raises the question of the need for storing all the existing daily data. If the work being carried out required only the mean monthly value then the storage of all daily data would be needless. Also, by observing the small variation between daily and monthly mean values, the assumption can be made that the mean monthly value is able to capture the characteristic features of the events happening at that groundwater monitoring station.

As with monthly data, elevation-duration curves may be obtained. These curves are based on the longest period of daily data and represent the **Percent of time** the groundwater is below a certain elevation (Figure 5.12). Again, this is not a probability but a percentage based on the available data. The daily elevation-duration curve should be more useful for evaluation of low water level records than the monthly mean values.

Figure 5.13 presents two SURFER plots of the monthly and daily values for the Caraquet observation well over its nine year

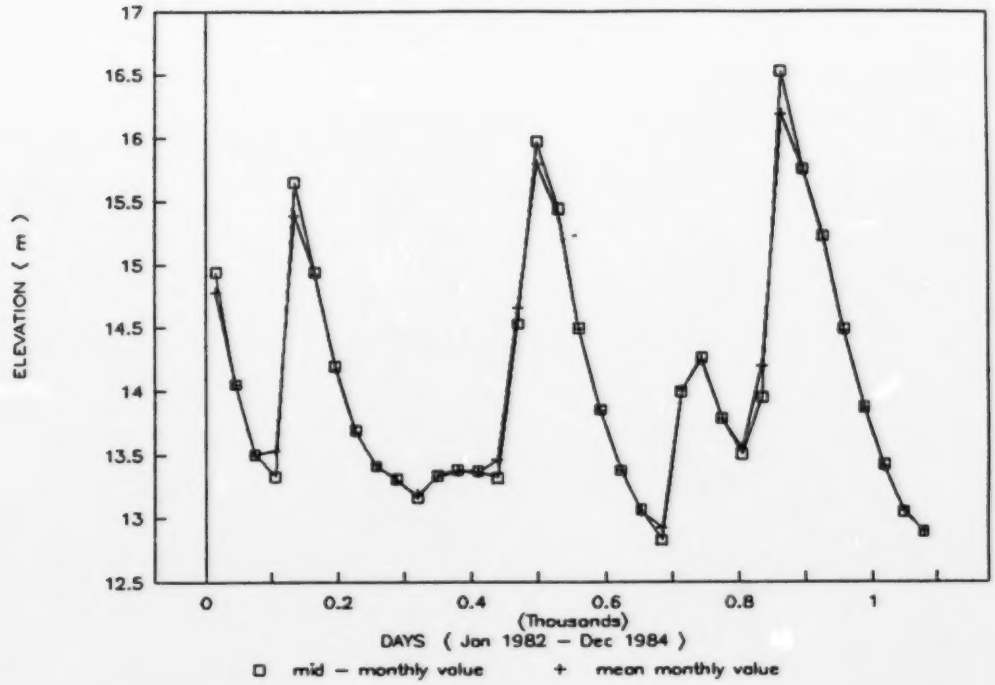

Figure 5.11 Comparison of mid-monthly and monthly mean groundwater levels at the Caraquet well between 1982-1984.

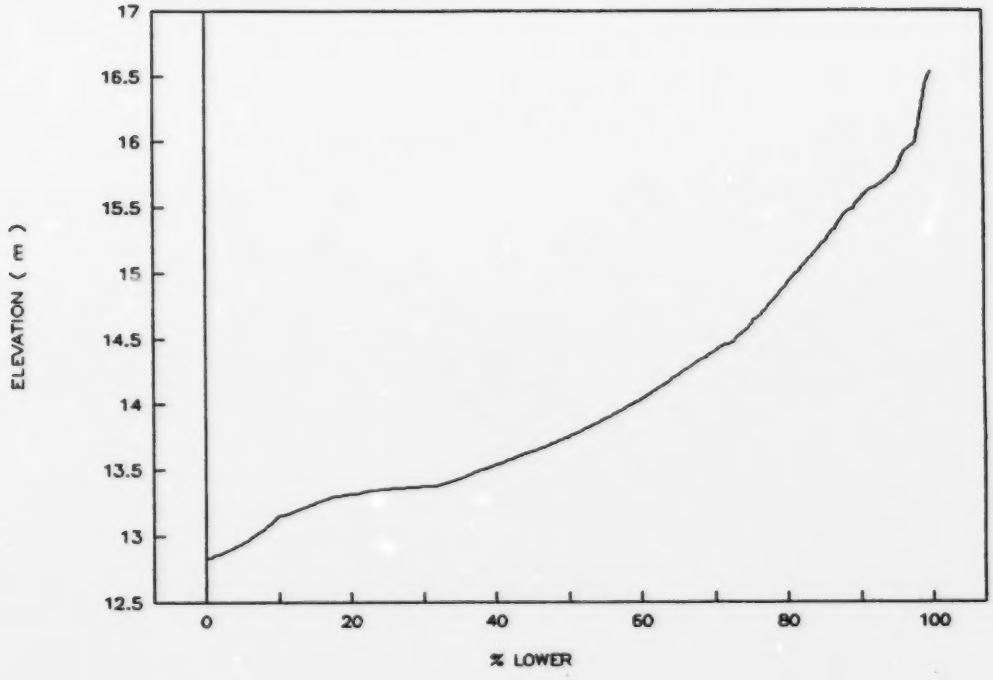

Figure 5.12 Elevation duration curve based on daily groundwater levels at the Caraquet observation well (1982 to 1984). Percent of time that the groundwater was below a certain elevation.

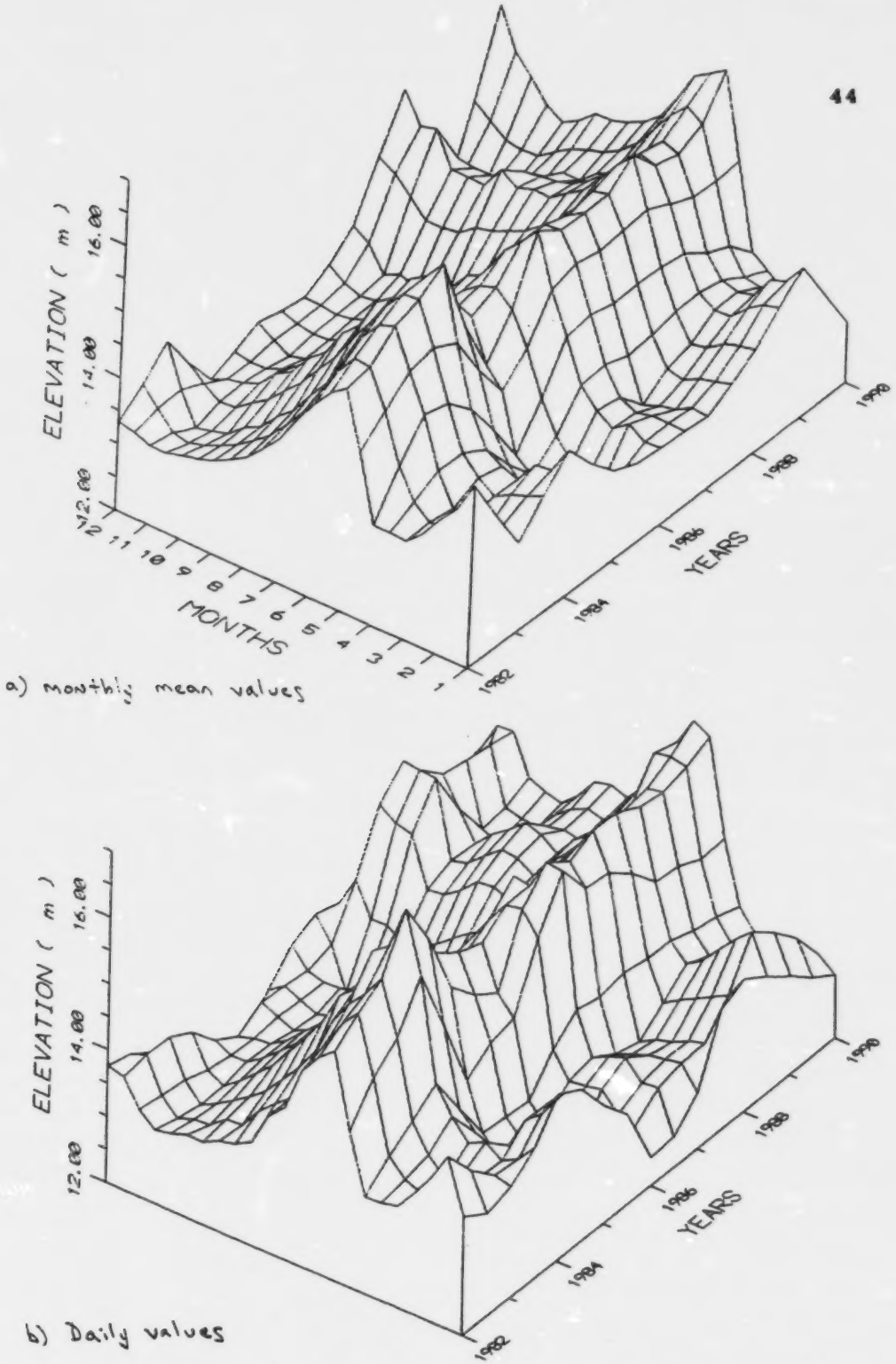

Figure 5.13 Comparison of the degree of accuracy when interpolating between monthly mean and daily values on SURFER. Caraquet observation well between 1982 - 1990.

period of record. Though there are missing data, comparisons of the monthly and daily SURFER plots show the difference in the degree of accuracy in representation between the two plots. Where SURFER has interpolated to fit 23 grid lines to 12 monthly values for each year, the results are not as representative as the plot where 23 grid lines are interpolated to 365 daily values for each year.

5.2.4 Hourly

Hourly data are recorded in order to monitor groundwater levels in a situation where the amount of water available is at a critical point or where the water level is changing rapidly with time. The New Maryland observation well (Well #AM-1) is affected by pumping and is considered to be critical (wells begin to go dry) if the water elevation drops below 92.0 metres. By monitoring the groundwater level every hour, NBDOE can evaluate the behaviour of the groundwater and be provided with real time hourly data so that they can release a water conservation notice.

By looking at the hourly data, each 24 hour period may be divided up and the groundwater levels linked to the water demands of the population. Figure 5.14 shows hourly groundwater level data obtained by the Telemark II recorder at the New Maryland well on July 11. At 6 AM the water level starts to decline as people begin

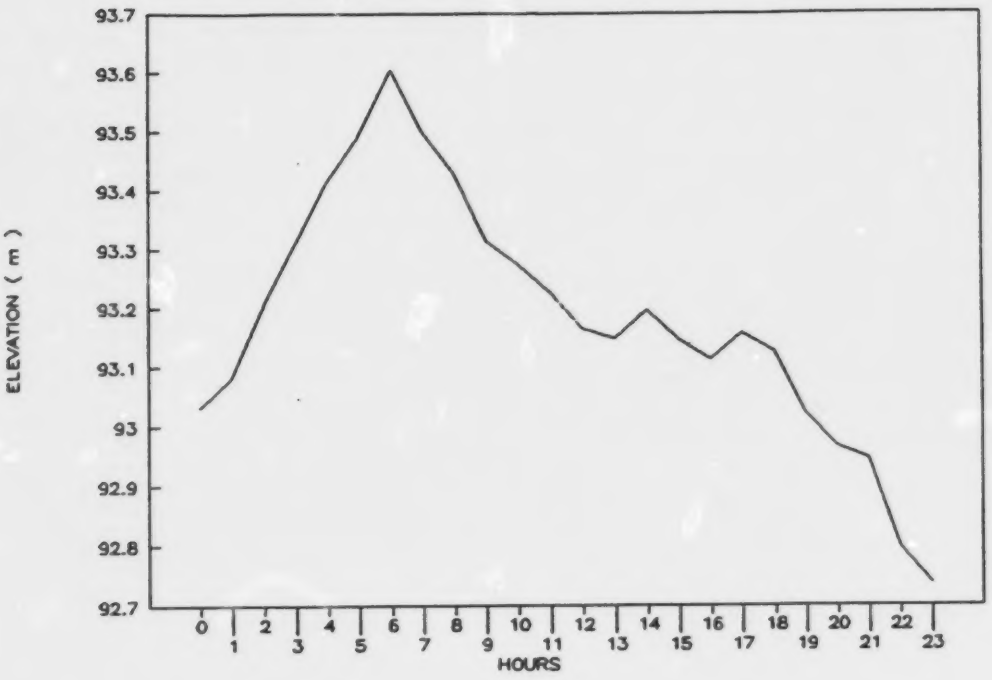

Figure 5.14 Hourly groundwater elevations for the New Maryland observation well on July 11, 1991.

the day. Water levels continue to decline until 1 PM, where it rises for about two hours and then steadily declines through supper and the evening as lawns are watered, cars washed, etc... This drop continues until 11 PM at which point people go to bed and the demand for water has decreased and the groundwater level begins to increase.

The daily New Maryland water level data are those values recorded at 12:00 (noon) each day. By using the 12:00 (noon) and daily mean values, a comparison can be made (Figure 5.15). This plot shows, that the 12:00 (noon) value used to characterize the groundwater for the day is misleading and suggests that an average value over the entire 24 hour period is more accurate. Though the 12:00 (noon) value is not representative of the daily groundwater behaviour for the New Maryland well, it must be remembered that this well is affected by pumping and at other wells in the network the 12:00 (noon) value may be considered as representative.

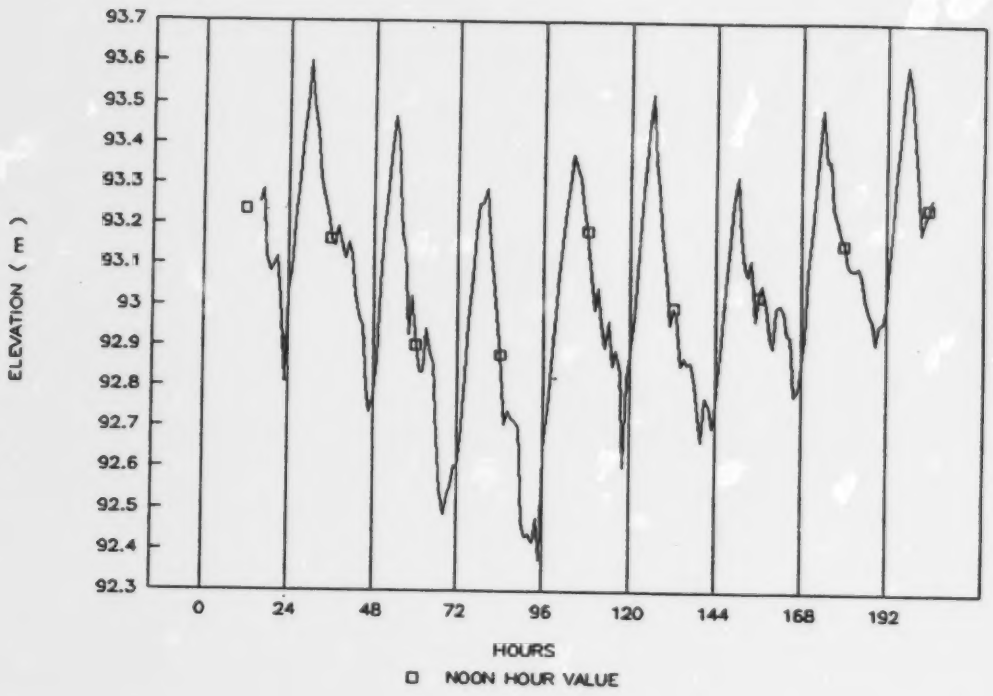

Figure 5.15 Comparison of hourly and noon hour groundwater elevations for the New Maryland observation well between July 10 and July 18, 1991.

6. RECHARGE

6.1 Introduction

This section provides an example of what may be done with the existing groundwater level data. Using the available hydro-meteorological data for the area of interest, the response of the groundwater levels to recharge is evaluated. Bray and MacLennan (1989) performed a similar study of this type for the Middle Branch Nashwaaksis Stream Basin, N.B.

The recharge process consists of inputs, outputs and storages. In order to evaluate the response of groundwater levels to recharge, the area of interest is studied as a control volume (study basin) in which the inputs into the control volume minus the outputs (Figure 6.1) are equal to the change in storage in the control volume for a specified period of time. The five factors to be considered are : rainfall, snowmelt, evapotranspiration, direct runoff, baseflow and groundwater levels.

The selection of the study site was based on the availability of a relatively shallow monitoring well that is not affected by pumping and has at least three complete years of daily data. The shallow well was a requirement because a near surface groundwater table was necessary to evaluate the response of well levels to recharge. The study basin was selected because it was the only

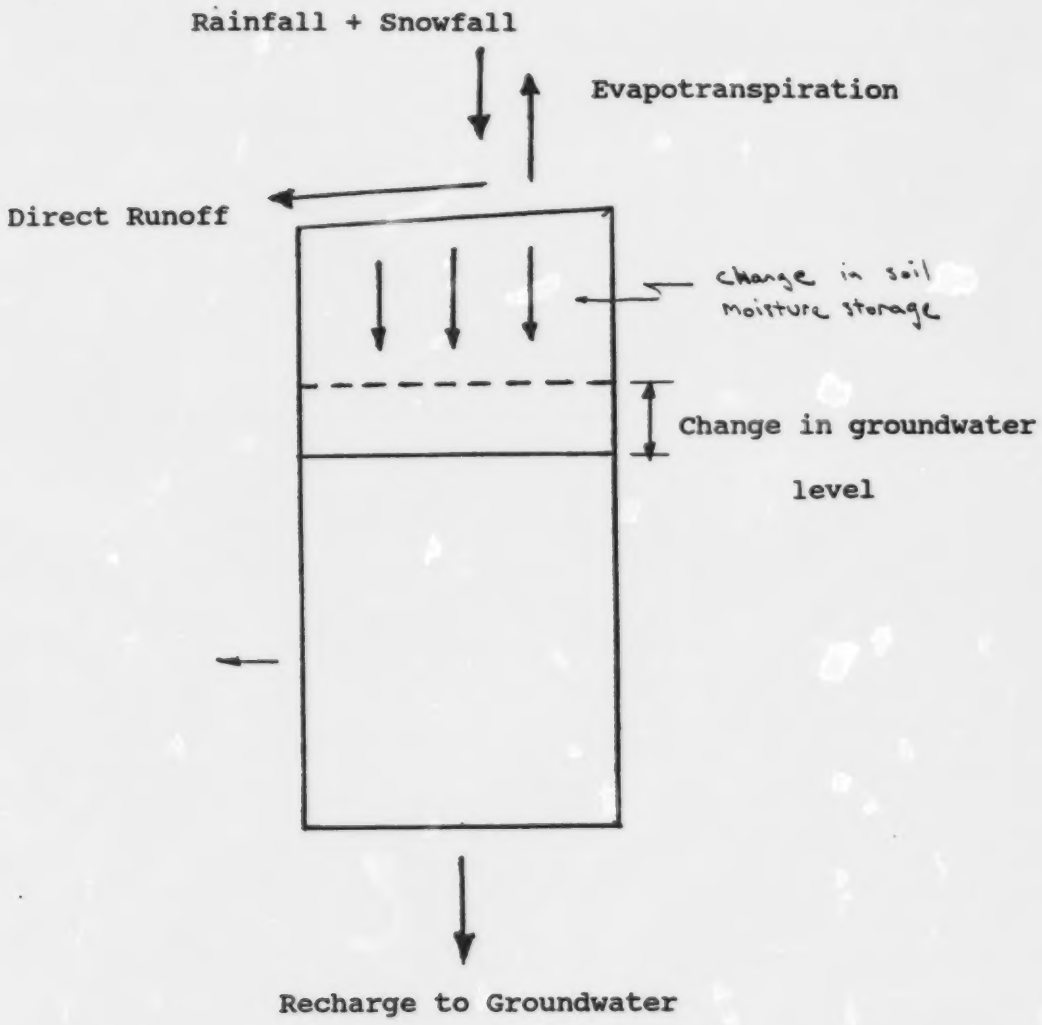

Figure 6.1 Control volume representing the river basin with inputs, outputs and storage.

gauged river near the well site.

Though the areas of interest (climate station, groundwater well site, hydrometric station) are not within the study basin, the assumption is made that the area is hydrologically homogeneous. In addition it is assumed that the monitoring well is in geological materials that are typical of the materials in the nearby drainage basin.

Although most of the data are available on a daily basis, the recharge estimates were evaluated on a monthly basis.

6.2 The Data

6.2.1 Description of Study Basin

The study basin is the Southwest Caraquet River Basin at Burnsville. The hydrometric station is located 21.1 km west of the Caraquet observation well (Figure 6.2) which is located outside the basin. The drainage basin as outlined in Figure 6.3 is approximately 177 km^2 which is approximately two percent larger than the published value of 173 km^2. The relief of the area is approximately 200 metres. About six percent of the basin surface is covered with swamps.

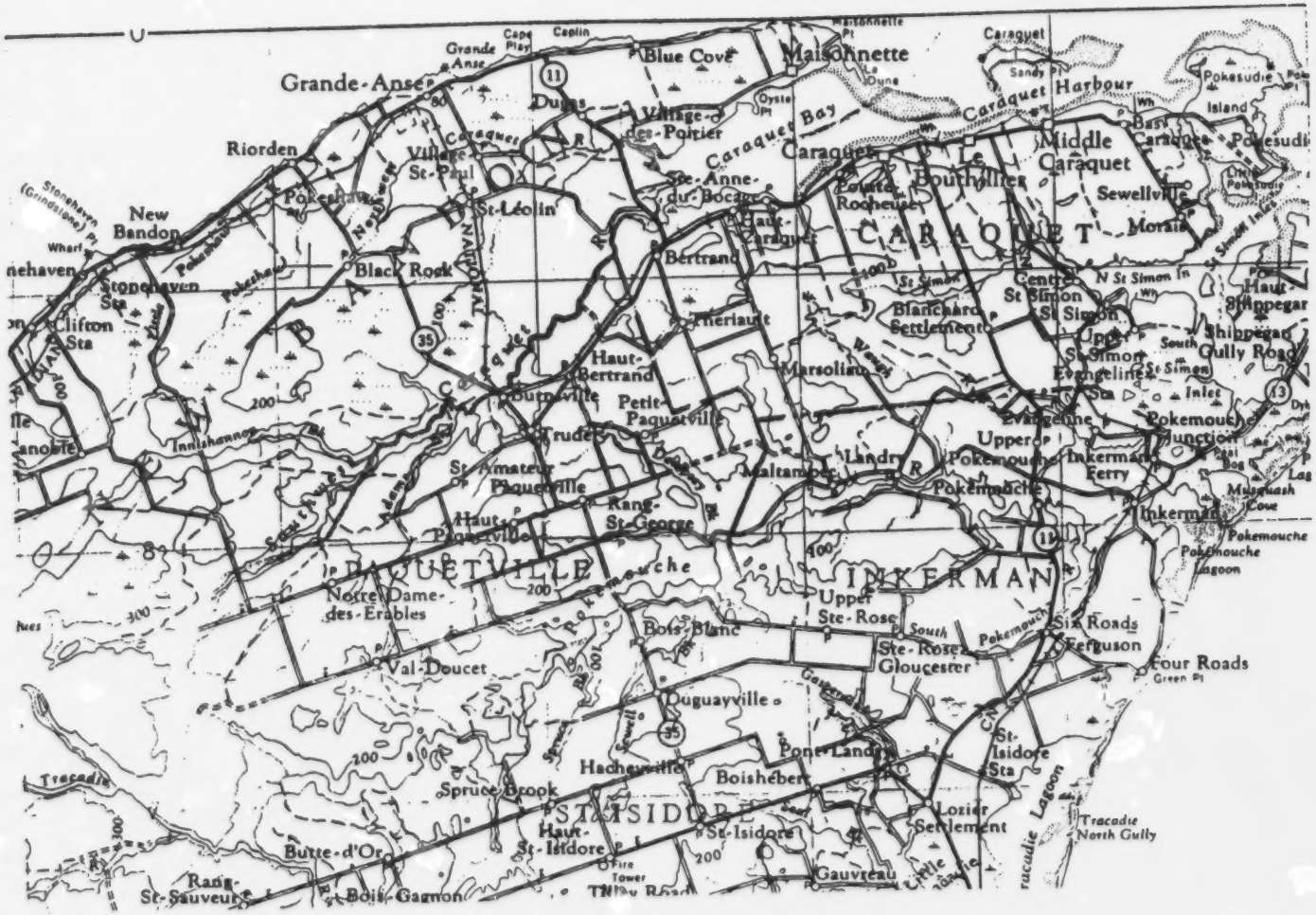

Figure 6.2 Map of northeastern New Brunswick locating the drainage basin, groundwater monitoring well and climate station.

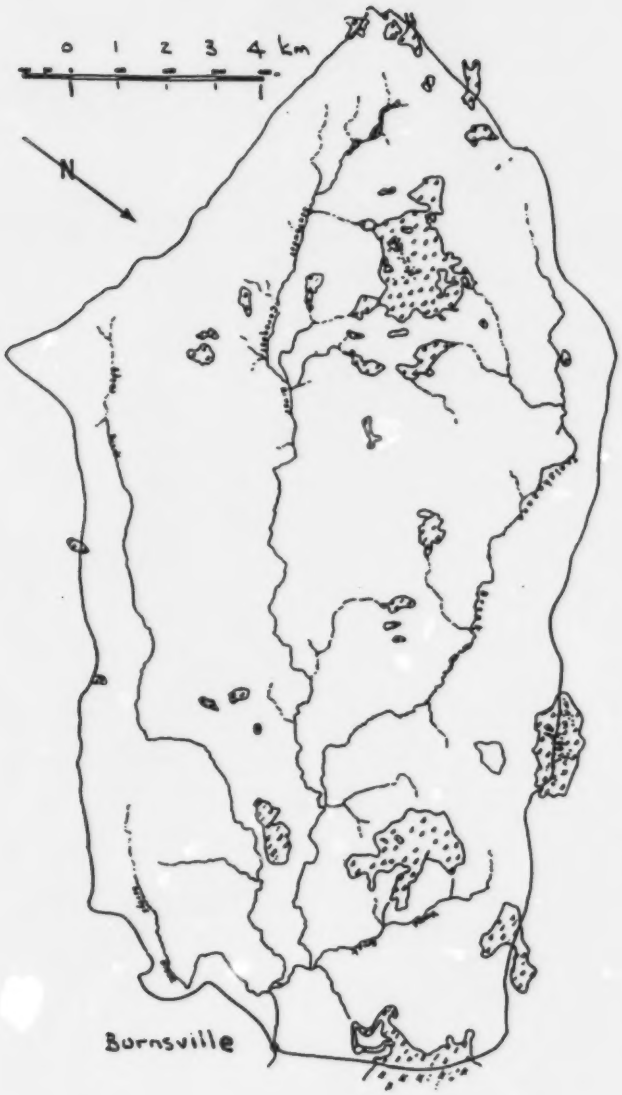

Figure 6.3 Representative drainage basin of Southwest Caraquet River at Burnsville, N. B.

The discharge data for the basin were obtained on disk through the Fredericton office of the Water Survey of Canada, Inland Waters Directorate, Environment Canada. These data are also found in the publication entitled "Surface Water Data Atlantic Provinces" published by Environment Canada.

6.2.2 Climate Station

During the period of study, January 1, 1982 - December 31, 1984, the climate station moved from Caraquet to Bas Caraquet. The distance between the two stations is 9.3 km, with the stations being 17.5 km and 26.4 km, respectively, to the east of the drainage basin.

The meteorological data for these stations was supplied through the publication "Monthly Record Meteorological Observation in Eastern Canada" published by Environment Canada. Though there was a change in the location of stations during the period of interest, the difference in overlapping data between the two stations for a two month period was quite small except for the value of rainfall (monthly temperatures differed by 0.1 and 0.5 degrees Celsius and rainfall amounts differed by 3.2 to 27.3 millimetres).

6.2.3 Observation Well

Although the monitoring well is maintained by the Inland Waters Directorate, Environment Canada, NBDOE has the daily well levels on file. The available record for the well started on January 1, 1982 and is available up to December 1990. The well is located approximately 21.1 km east of the study basin and approximately mid distance between the two climate stations.

6.3 Recharge to Groundwater

6.3.1 Net Inputs

The net input to the groundwater for the accounting period of one month, is evaluated as follows, under the assumption that there is no change in soil moisture storage in the unsaturated zone:

$$NI = RFI + SMI - ET$$

where NI = the net input to groundwater storage.

RFI = the months rainfall that enters the ground surface.

SMI = the monthly snowmelt that enters the ground surface

ET = the actual evapotranspiration

For application purposes, the above equation is written as :

$$NI = a*RF + b*SM - c*PET$$

where RF = monthly rainfall

SM = monthly snow melt

PET = monthly potential evapotranspiration

a = coefficient that accounts for the fraction of rainfall that infiltrates.

b = coefficient that accounts for the fraction of snowmelt that infiltrates.

c = coefficient that accounts for the fraction of evapotranspiration that actually occurs.

For this study, the coefficients were considered to be equal to 1.0. That is, all the rainfall and snowmelt were considered to act as total inputs and that the actual evapotranspiration was equal to potential evapotranspiration.

The net inputs for one year at the Caraquet climate station are characterized by the bar chart shown in Figure 6.4. The recharge expected in the spring months is shown as a large input, while the negative values indicate that evapotranspiration is greater than the amount of rainfall (no recharge) during that particular month.

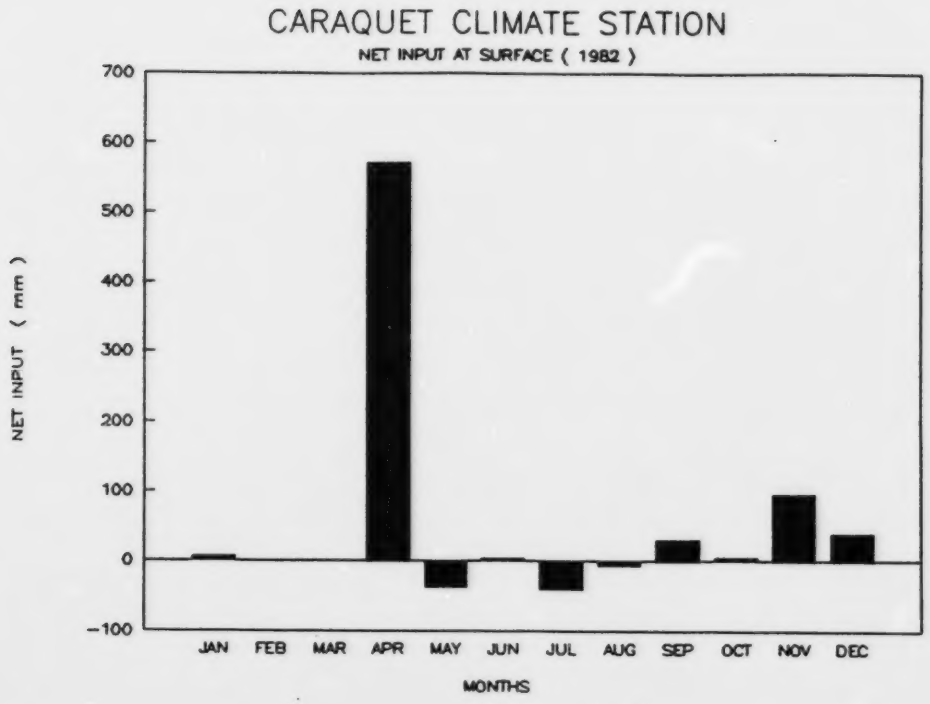

Figure 6.4 Monthly net inputs into the ground surface. Based upon data from Caraquet climate station in 1982. (See text for assumptions).

These results appear to be reflected by the behaviour of the groundwater (Figure 6.5). When the monthly net inputs are overlaid on the groundwater elevation graph they appear to match if the net input graph is lagged by approximately one month.

6.3.2 Surface Inputs

Estimates of the net inputs at the surface were based upon rainfall, snowmelt and temperature. Before calculation of the amount of water available for input, the snow must first be converted from **centimetres of snow** on the ground at the end of the month, to **millimetres of water** equivalent. The assumptions used to convert snowfall (SF) to snow water equivalent (SWE) were: snow has a bulk density of 0.20 up to the end of February, 0.25 for the month of March and 0.30 from the first of April till the end of the melt season. These values are based on work by Daugharty (1984). The computation of SWE is based on the following equation:

$$SWE_i = \left(\frac{\rho_s}{\rho}\right) * SF_i$$

Calculation of the amount of input at the surface required the assumption that an amount of the rainfall, during the months with a mean temperature below zero degrees C, would be retained in the snow pack. The amount retained represents the liquid holding capacity of the snow pack and is based on a percentage of the

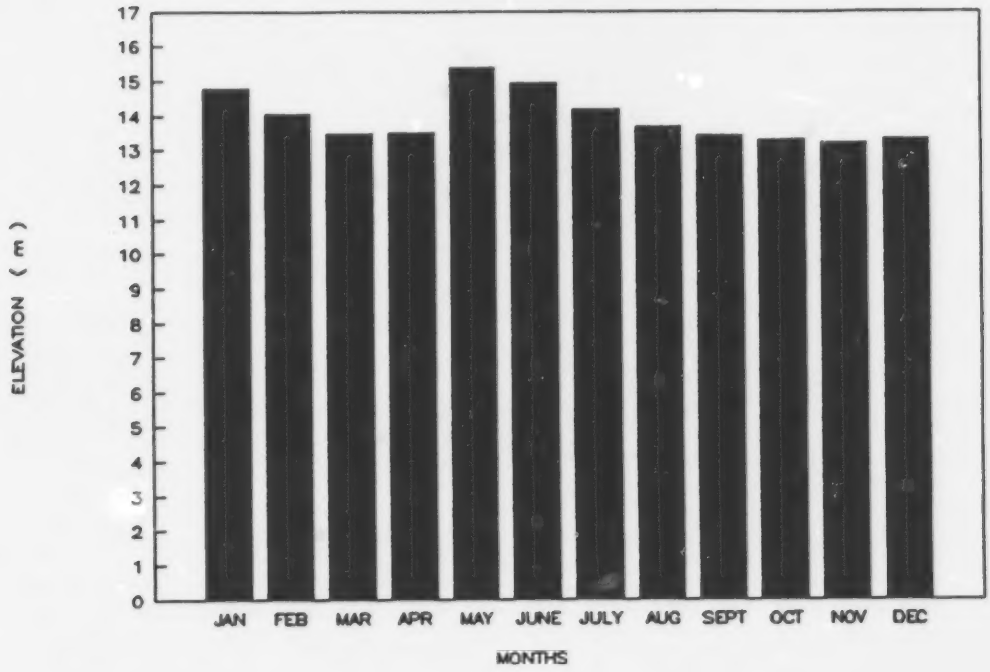

Figure 6.5 Caraquet groundwater levels for 1982. Note how the levels appear to be affected by the net inputs in Figure 6.4.

cumulative snowfall and previously retained rainfall for the year. The liquid holding capacity of a ripe snowpack was assumed to be 0.05 of the snow water equivalent (U.S. Army Corps of Engineers, 1960). In the first month of the year that had a mean temperature above zero degrees C, the total precipitation for the month plus the cumulative snow and retained rainfall were considered to act as an input. The major input represented the largest recharge event. In most cases this large input was expected to occur in the months of March and April of each year (see Appendix B).

6.3.3 Potential Evapotranspiration

Estimates of potential evapotranspiration where made using Thornthwaite's formulae. This method is based on an area that has short, close set vegetation with an adequate water supply, in the latitudes of the United States (Wilson, 1974). Calculation of the potential evapotranspiration (PET) was carried out using the following formulas (see Appendix B):

$$j_i = \left(\frac{t_n}{5}\right)^{1.514}$$

$$J = \sum_{1}^{12} j_i$$

$$PET_x = 16\left(\frac{10\,t}{J}\right)^a \text{ mm per month}$$

where

$$a = (675 \times 10^{-9})\,J^3 - (771 \times 10^{-7})\,J^2 + (179 \times 10^{-4})\,J + 0.492$$

Where PET is a theoretical standard monthly value based on thirty days in a month and 12 hours sunshine per day. This value was adjusted with a correction coefficient for non standard conditions, that is for months not having thirty days and not having twelve hours daily sunshine (Gray, 1970).

6.4 Discharge

6.4.1 Water Balance

Hydrographs of the river outflow from the basin were plotted from the daily discharge data obtained from the Water Survey of Canada, Inland Waters Directorate, Environment Canada.

The monthly discharge data for the basin were obtained from the "Surface Water Data Atlantic Provinces" published by Environment Canada. Based upon the published area of the basin (173 km^2), the total runoff for each month was determined using the following formula:

$$RO = \frac{VRO}{Ad}$$

where RO = the depth of runoff expressed in mm over the entire drainage area.

VRO = the volume of runoff in dam^3

Ad = the total drainage area of the basin in km ^2.

Calculation of the monthly water balance requires information concerning the change in groundwater levels over the month, the amount of monthly rainfall, snowmelt and evapotranspiration. Using the following equation :

Net inputs - Runoff = Change in gw levels * porosity

$$(RF + SM - ET) - RO = \Delta H * n$$

where:

RF = rainfall, mm

SM = snowmelt, mm

ET = evapotranspiration, mm

RO = total runoff, mm

ΔH = change in groundwater elevation, mm

n = porosity of material (sandstone)

[sandstone: 0.05 - 0.3 (Freeze and Cherry, 1979)]

For this case, a value of porosity equal to 0.05 was selected for the sandstone in which the monitoring well is located.

Using the calculations for net inputs (NI) and the difference

in groundwater levels (ΔH) on the first of every month and assuming that the lag between recharge and groundwater levels is equal to zero, the above equation becomes :

$$RO = NI - \Delta H * n$$

The estimated monthly total runoffs are calculated and are compared to the published values (Figure 6.6) to indicate how well the model represents the actual total runoff.

The equation may also be rewritten to determine the value of porosity for the material in which the well is located.

6.4.2 Base Flow Separation

To determine the component of baseflow and direct runoff in the total runoff as measured at the hydrometric station, a base flow separation was carried out.

Calculation of the base flow was done for the three year period, January 1982 - December 1984. To calculate the base flow, the logarithm of the discharge was plotted against an expanded time scale (each graph containing 50 days) (Figure 6.7). To obtain the point from which runoff was considered to effectively become baseflow, the following equation was used:

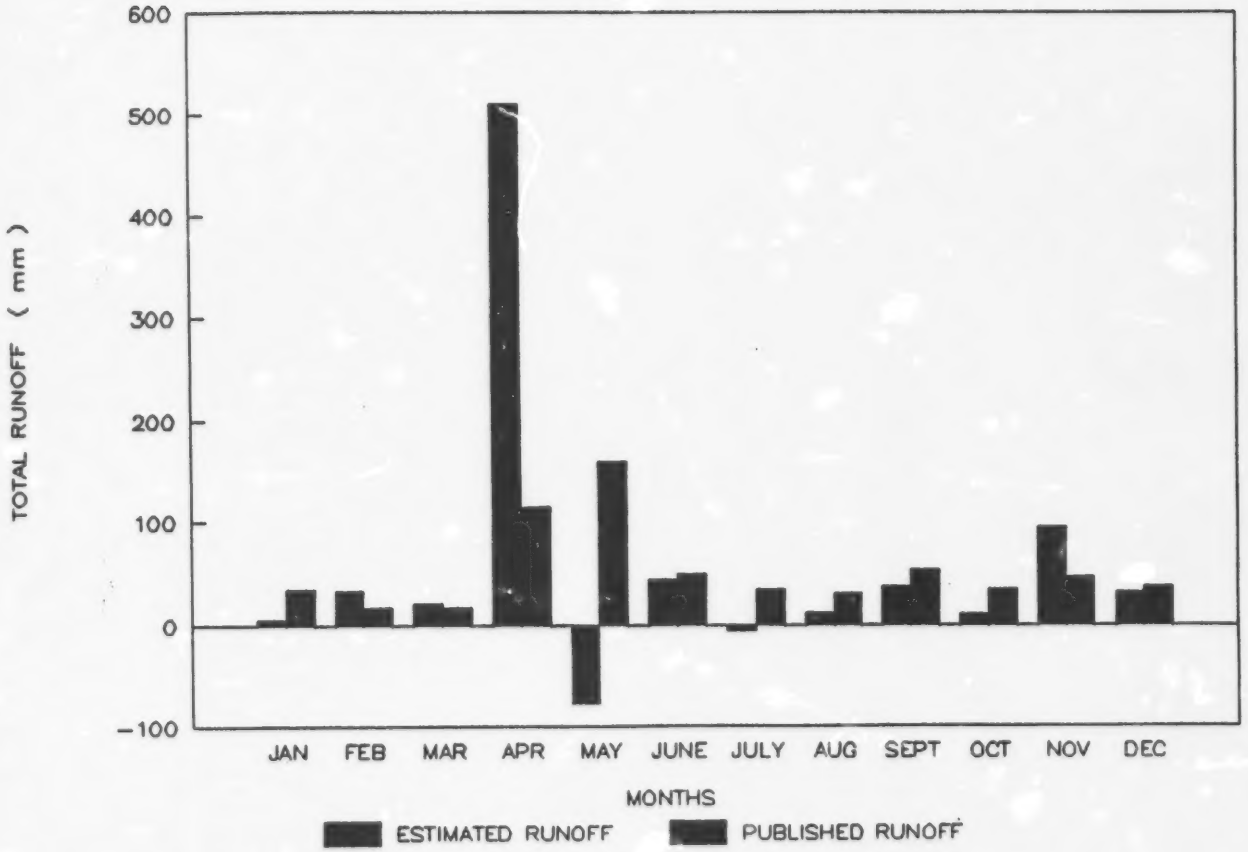

Figure 6.6 Comparisons of estimated runoff with published values of runoff in the Southwest Caraquet river at Burnsville (1982-1984).

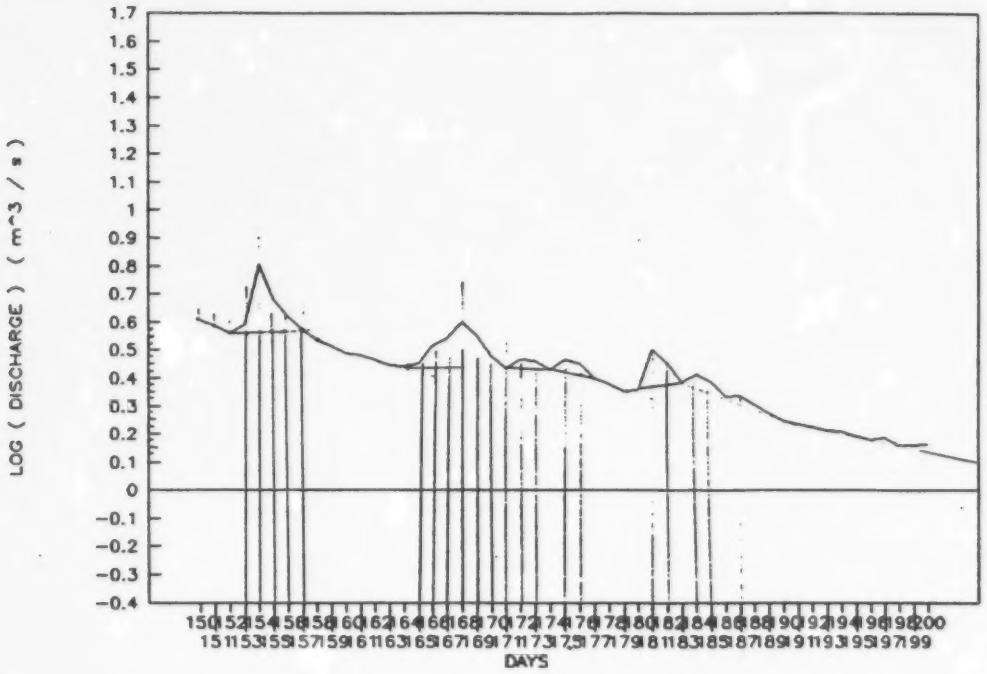

Figure 6.7 Example of base flow separation with log discharge and expanded time scale.

$$N = Ad^{0.2}$$

where Ad = drainage area in miles ^2.

The point after the peak flow at which surface runoff has effectively ceased is taken to be N days and a straight line is drawn from that point to the point of sudden rise (Wilson, 1969) (Figure 6.8). The value of N for the study basin was found to be 2.3 days. Because of the relatively large percentage of swamps (surface water) in the basin, the time from peak to where the slope changes appears to range from one to four days. With this variability, the above method using N equal to 3 days was selected.

Though there are errors associated with this method of base flow separation, the range of error is small when examining the log scale for most of the flows (low flows below log 1). Also the method used was consistent throughout.

6.4.3 Well Levels and Base Flow

Figure 6.9 shows the behaviour of well levels and base flow. The peaks in the groundwater levels occur within 10 days after the peaks in the base flow. This indicates that the groundwater levels at Caraquet reflect the response of the groundwater flow system of the Southwest Caraquet River Basin.

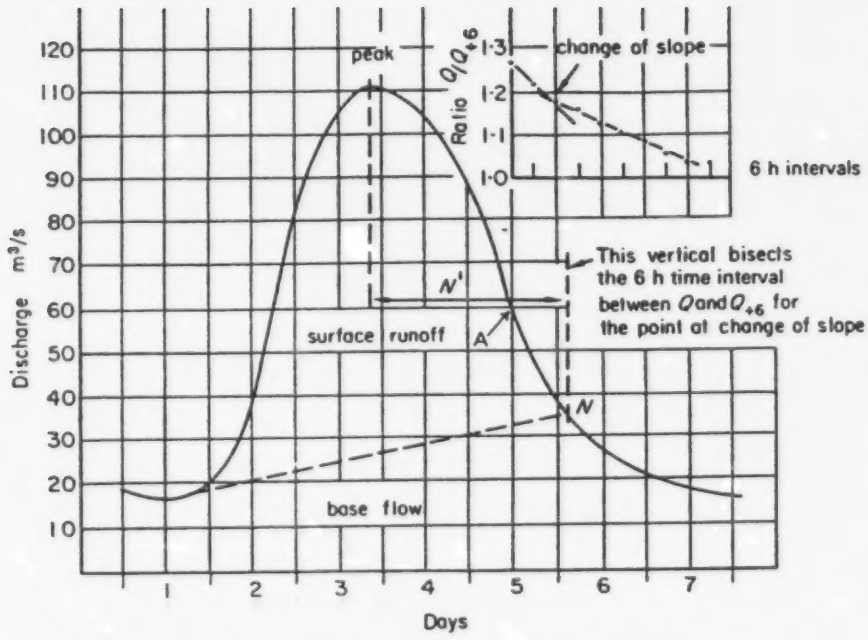

Figure 6.8 Base flow separation method. Where N is the number of days after the peak to the time at which the slope of the discharge changes and flow is considered to be all base flow (from Wilson, 1974).

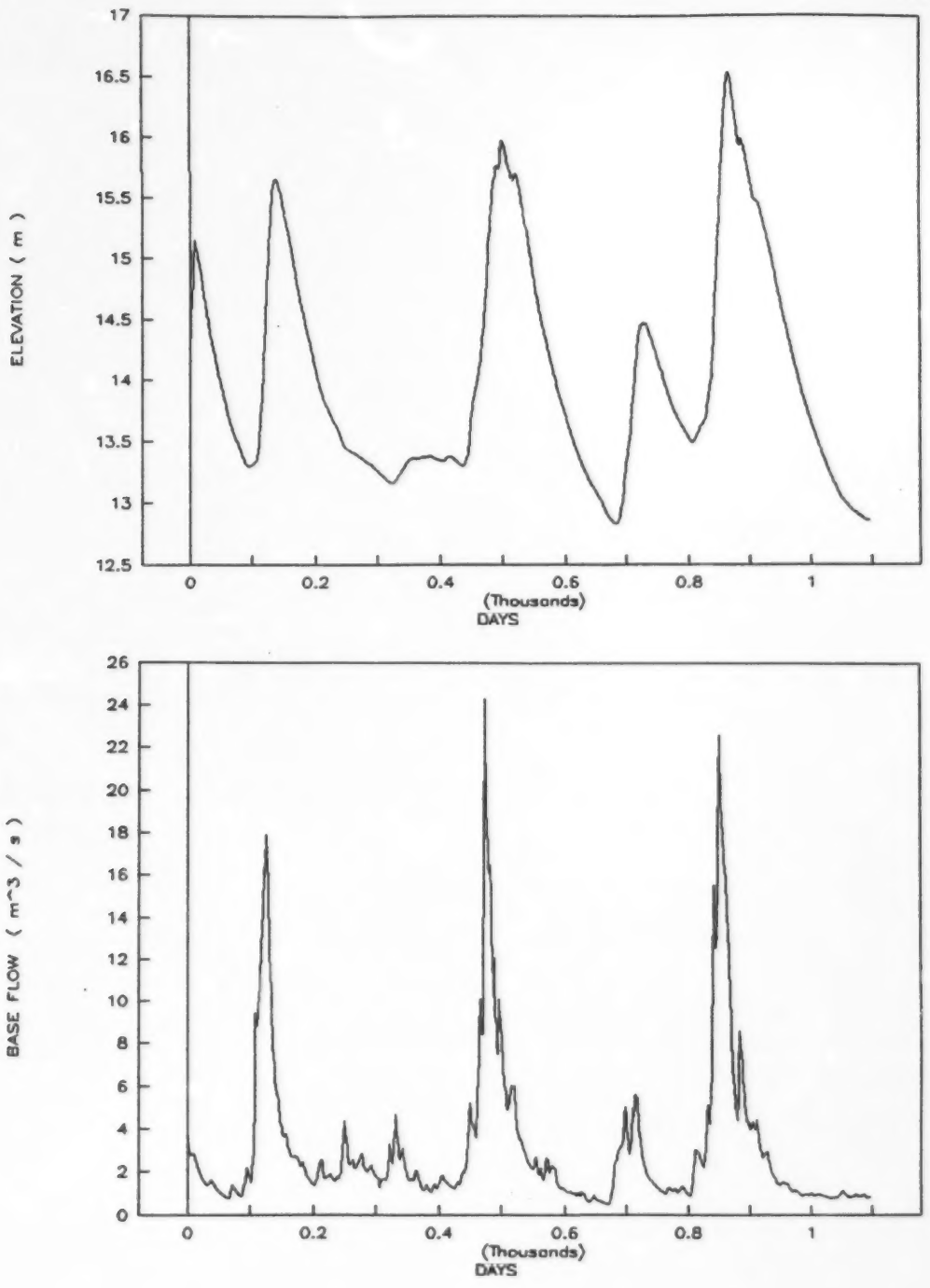

Figure 6.9 Comparisons of base flow in the Southwest Caraquet River Basin and groundwater levels at the Caraquet observation well.

6.5 Base Flow Recession Constants

From the daily discharge data, discharge recession constants were determined using the following equation :

$$Log\,Q - Log\,Q_0 = (t - t_0) * Log\,K_{rQ}$$

where Q = base flow discharge at time t

Q_0 = base flow discharge at time t_0

K_{rQ} = recession constant for discharge.

The recession constants were calculated for the major recharge events of each year. For the three periods the values of K_{rQ} ranged from 0.973 to 0.981, with the mean being approximately 0.98.

Once the recession coefficient is determined for a given hydrometric station, it is possible to make predictions about the future behaviour of the discharge based on a present value and under the assumption that no direct runoff occurs over the period of interest. This method may also be applied to groundwater levels for predicting the lowest levels that may occur after a given period of time or for approximating the groundwater levels where data are missing under the assumption that no recharge occurs over the period of interest. The recession constant obtained for groundwater recession at a monitoring well are associated with a specified datum for that well.

7. SUMMARY

The groundwater monitoring network in New Brunswick contains 36 actively monitored wells, of which over three quarters are managed by NBDOE. All but 11 of the 36 wells are equipped with recorders.

A long-term analyses of the groundwater levels for selected monitoring wells was performed. The analyses of the groundwater levels added to the existing data base and demonstrated how the existing data may be used to further characterize the groundwater levels in the selected areas. The results obtained provided a visual representation of the groundwater levels over the period of record and allowed for general statements to be made about the behaviour of the groundwater in the vicinity of the well. Demonstrations of the varying degrees of accuracy (yearly, monthly, daily, hourly) of recording data were carried out. For example, the groundwater regime defined by the mean monthly values closely approximates the behaviour exhibited by a seven-day moving average. The regime characterized by the single mid-month value and the mean monthly value compare favourably with the daily record. The single mid-month value appears to be slightly better than the mean monthly value at representing the behaviour of the groundwater levels.

A method has also been presented to evaluate the response of groundwater levels to recharge from rainfall, snowmelt and

evapotranspiration. This method is based on easily obtainable information and is meant to demonstrate another use of data from the groundwater monitoring network.

The method presented concerning the response of wells to recharge may not be correct because of the assumptions that had to be made concerning the estimated percent net input to groundwater. In addition the monitoring well and climate station were outside the river basin. Even with these limitations, comparisons between the estimated and published total runoffs indicated that the model presented was representative except during the primary recharge event occurring in the spring. Similar comparisons between baseflow and groundwater levels also indicated that the model reflected the behaviour of events in the drainage basin. These examples illustrate what may be done using the available groundwater data and suggests that NBDOE should consider locating shallow monitoring wells in gauged river basins with nearby climatic stations.

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LIST OF REFERENCES

Brinsmead, R.A. 1984. Review of groundwater level monitoring network in New Brunswick. Water Resources Branch, New Brunswick Department of Municipal Affairs and Environment, Fredericton, NB, 90 p.

Daugharty, D.A. 1984. The effects of topography and forest cover on snow depths and water equivalents in the Nashwaak Experimental Watershed, New Brunswick. M.Sc.F. Thesis. Department of Forest Resources, University of New Brunswick, Fredericton, NB, 256 p.

Domenico, P.A. and Schwartz, F.W. 1990. Physical and chemical hydrogeology. John Wiley and Sons, New York, NY.

Freeze, R.A. and Cherry, J.A. 1979. Groundwater. Prentice-Hall, Englewood Cliffs, NJ, 604 p.

Golden Software Inc. 1990. SURFER version 4 reference manual. Golden Software Inc., Golden, CO.

Gray, D.M.(ed). 1970. Handbook on the principles of hydrology. Canadian National Committee for the International Hydrological Decade, Ottawa, ON.

MacLennan, H.M. and Bray, D.I. 1989. Evaluation of surface-subsurface interaction for the Middle Branch Nashwaaksis Stream Basin, N.B. Proceedings, 9th Canadian Hydrotechnical Conference, St. John's, NF, June 8-10. Vol. II (Hydrotechnical), pp. 578-598.

U.S. Army Corps of Engineers. 1960. Runoff from snowmelt. EM 1110-1-1406, Engineering and design manuals, Portland, OR, 75 p.

Wilson, E.M. 1974. Engineering Hydrology. Macmillan Press Ltd., London, UK. 232 p.

APPENDICES

APPENDIX A

FILES

A.1 Storage

All files are stored in separate sub-directories based upon well names. The following is a listing of all the sub- directories used and their definitions :

Sub-Directory	Definition
CHTAIR	CHATHAM AIR BASE
CHTIND	CHATHAM INDUSTRIAL PARK
CHTRCP	CHATHAM R.C.P
NWMARY	NEW MARYLAND
TRACADIE	TRACADIE
LAMEQUE	LAMEQUE
CARAQT	CARAQUET
SHPPGN	SHIPPEGAN

Within each sub-directory are the data files from which all the intermediate files may be produced. These files are recorded by year and contain the daily data for that particular year. These files are stored as:

CHTAIR

CHTAIR78.WK1 CHTAIR85.WK1

CHTAIR79.WK1 CHTAIR86.WK1

CHTAIR80.WK1
CHTAIR81.WK1
CHTAIR82.WK1
CHTAIR83.WK1
CHTAIR84.WK1
CHTAIR87.WK1
CHTAIR88.WK1
CHTAIR89.WK1
CHTAIR90.WK1
CHTAIR91.WK1

CHTIND

CHTIND82.WK1
CHTIND83.WK1
CHTIND84.WK1
CHTIND85.WK1
CHTIND86.WK1
CHTIND87.WK1
CHTIND88.WK1
CHTIND89.WK1
CHTIND90.WK1
CHTIND91.WK1

CHTRCP

CHTRCP81.WK1
CHTRCP82.WK1
CHTRCP83.WK1
CHTRCP84.WK1
CHTRCP85.WK1
CHTRCP86.WK1
CHTRCP87.WK1
CHTRCP88.WK1
CHTRCP89.WK1
CHTRCP90.WK1
CHTRCP91.WK1

NWMARY

NWMRY79.WK1
NWMRY80.WK1
NWMRY81.WK1
NWMRY82.WK1
NWMRY83.WK1
NWMRY86.WK1
NWMRY87.WK1
NWMRY88.WK1
NWMRY89.WK1
NWMRY90.WK1

NWMRY84.WK1
NWMRY85.WK1
NWMRY91.WK1

TRACADIE

TRAC82.WK1
TRAC83.WK1
TRAC84.WK1
TRAC85.WK1
TRAC86.WK1
TRAC87.WK1
TRAC88.WK1
TRAC89.WK1
TRAC90.WK1

LAMEQUE

LAMQ82.WK1
LAMQ83.WK1
LAMQ84.WK1
LAMQ85.WK1
LAMQ87.WK1
LAMQ88.WK1
LAMQ89.WK1
LAMQ90.WK1

CARAQT

CQT82.WK1
CQT83.WK1
CQT84.WK1
CQT85.WK1
CQT86.WK1
CQT87.WK1
CQT88.WK1
CQT89.WK1
CQT90.WK1

SHPPPGN

SHP82.WK1
SHP83.WK1
SHP87.WK1
SHP88.WK1

SHP84.WK1	SHP89.WK1
SHP85.WK1	SHP90.WK1

A.2 DATA MANIPULATION

To manipulate the data, a knowledge of LOTUS and its available functions is necessary. All the data manipulation required to produce the results obtained were done using LOTUS. The above files, once created, can be manipulated to produce the results in the report.

APPENDIX B

RECHARGE CALCULATIONS

Examples of the calculations that were done are included on the attached spreadsheet. The spreadsheet used was created as a template for which other years of data may be entered and the results calculated. The worked example is for the Caraquet climate station, and Southwest Caraquet River in 1982. Below are the formulas and explanations of the calculations performed.

B.1 Potential Evapotranspiration

Calculations of potential evapotranspiration were done using the following formulas :

$$j_i = \left(\frac{t_n}{5}\right)^{1.514}$$

$$J = \sum_{1}^{12} j_i$$

$$a = (675 * 10^{-9}) * J^3 - (771 * 10^{-7}) * J^2 + (179 * 10^{-4}) * J + 0.492$$

$$PET = 16\left(\frac{10t}{J}\right)^{a}$$

B.2 Surface Inputs

Conversion of centimetres of snow to millimetres of snow water equivalent was done by multiplying the monthly snowfall by the estimated bulk density of the snow for that month (for example, for the months of January and February bulk density is equal to 0.2). If the snowfall for January was 135 cm, then the snow water equaivalent of the snow pack is computed to be

(135* 0.2 * 10) 270 mm of water.

The calculations for surface inputs, shown on the spreadsheet contain the following terminology. Definitions of the terminology used are listed below.

TERM	DEFINITION
RAIN (- TEMP)	Amount of rain in months with temp. at or below zero degrees C.
PCP (+ TEMP)	Amount of precipitation in months with temp. above zero degrees C.
SNOW (- TEMP)	Amount of snow in months with temp. at or below zero degrees C.
SNOW CUMULAT.	Total amount of accumulated snow.
CUMULAT. SNOW + RETAINED	Total amount of accumulated snow and retained rainfall.
POTENT. RETAINED	Potential amount of rainfall that may be retained in the snowpack.
ACTUAL RETAINED	Amount of rainfall that was retained in the snowpack.
RECHARGE TO GROUNDWATER	The amount of water available for recharge.

The method used, assumes that rainfall is retained in the snowpack during the months with a mean temperature at or below zero degrees Celsius. The amount of rainfall retained is taken to be five percent of the accumulated snowpack plus previously retained rainfall. The first month that has a mean temperature above zero degree Celsius is considered to have all of the accumulated snowpack plus retained rainfall go into recharge. This allows for a large input to occur in April.

During the months with a mean temperature above zero degrees Celsius, all total precipitation is considered to be available for recharge.

B.3 Net Inputs

Net inputs into the groundwater were based upon the results obtained from the calculations of potential evapotranspiration (PET) and surface inputs (rainfall (RF) and snowfall (SF)). The formulae used to calculate the net inputs is (RF + SM - PET).

LOCATION:1983 CLIMATE STATION AT CARAQUET

	TOTAL VALUES			MONTHLY MEAN TEMPERATURE		
	RAIN	SNOW	PCP	MAX	MIN	MEAN
	(mm)	(mm)	(mm)	degree Celsius		
JAN	29.2	150.0	104.2	-3.6	-10.5	-7.0
FEB	13.4	146.0	86.4	-4.1	-12.2	-8.2
MAR	80.5	67.5	107.5	0.6	-6.0	-2.7
APR	87.4	11.0	98.4	6.1	-0.3	2.9
MAY	126.8	0.0	126.8	11.4	3.6	7.5
JUN	12.4	0.0	12.4	21.4	10.8	16.1
JUL	111.7	0.0	111.7	23.1	14.0	18.5
AUG	78.6	0.0	78.6	22.8	14.2	18.5
SEP	69.6	0.0	69.6	18.9	9.8	14.4
OCT	43.6	0.0	43.6	11.8	4.3	8.0
NOV	170.4	37.0	207.4	4.7	0.3	2.5
DEC	86.5	84.0	128.5	-3.2	-9.8	-6.5
TOTAL	910.1	495.5	1175.1	109.9	18.2	64.0
MEAN	75.8	41.3	97.9	9.2	1.5	5.3

% RAINFALL TO BE RETAINED IN SNOW = 5

RAIN (- TEMP) (mm)	PCP (+ TEMP) (mm)	SNOW (- TEMP) (mm)	SNOW CUMULAT. (mm)	CUMULAT. SNOW + RETAINED (mm)	POTENT. RETAINED (mm)	ACTUAL RETAINED (mm)	RECHARGE (mm)
29.2	0.0	150.0	150.0	150.0	7.5	7.5	21.7
13.4	0.0	146.0	296.0	303.5	15.2	13.4	0.0
80.5	0.0	67.5	363.5	384.4	19.2	19.2	61.3
0.0	98.4	0.0	0.0		0.0	0.0	502.0
0.0	126.8	0.0	0.0		0.0	0.0	126.8
0.0	12.4	0.0	0.0		0.0	0.0	12.4
0.0	111.7	0.0	0.0		0.0	0.0	111.7
0.0	78.6	0.0	0.0		0.0	0.0	78.6
0.0	69.6	0.0	0.0		0.0	0.0	69.6
0.0	43.6	0.0	0.0		0.0	0.0	43.6
0.0	207.4	0.0	0.0		0.0	0.0	207.4
86.5	0.0	84.0	84.0	84.0	4.2	4.2	82.3
							1317.4

Figure B.1 Example of spreadsheet template for calculating recharge, potential evapotranspiration and monthly runoff.

MONTHLY HEAT INDEX i		PE per month PET (mm)	Corection Coeff.	Adjusted PE per month (mm)
JAN	0	0	0.795666	0
FEB	0	0	0.746666	0
MAR	0	0	1.054	0
APR	0.438359	15.47598	1.14	17.64262
MAY	1.847575	39.19250	1.343333	52.64839
JUN	5.873456	82.72496	1.32	109.1969
JUL	7.248654	94.76521	1.384666	131.2182
AUG	7.248654	94.76521	1.271	120.4465
SEP	4.960440	74.17270	1.05	77.88133
OCT	2.037218	41.74575	0.961	40.11767
NOV	0.350139	13.38519	0.78	10.44045
DEC	0	0	0.754333	0
J =	30.00449			
a =	0.977902			

RECHARGE TO GW (rainfall + snowmelt - PET) (mm)
21.7
0.0
61.3
484.4
74.2
-96.8
-19.5
-41.8
-8.3
3.5
197.0
82.3
757.8

DRAINAGE BASIN AREA (m^2) = 1.7E+08

	DISCHARGE (m^3)	TOTAL RUNOFF (m)	(mm)
JAN	3700000	0.021387	21.4
FEB	3740000	0.021618	21.6
MAR	8050000	0.046531	46.5
APR	36800000	0.212716	212.7
MAY	22900000	0.132369	132.4
JUN	10400000	0.060115	60.1
JUL	6350000	0.036705	36.7
AUG	4160000	0.024046	24.0
SEP	2590000	0.014971	15.0
OCT	1870000	0.010809	10.8
NOV	10400000	0.060115	60.1
DEC	13100000	0.075722	75.7
			717.1

Figure B.1 (continued) Example of spreadsheet template for calculating recharge, potential evapotranspiration and monthly runoff.